This document is guaranteed to be current only to issue date.

Some Mars Global Surveyor documents that relate to flight operations are under revision to accommodate the recently modified mission plan.

Documents that describe the attributes of the MGS spacecraft are generally up-to-date.

Mars Global Surveyor Project

MISSION SEQUENCE PLAN

Preliminary Version (MGS 542-407)

September 1995

Jet Propulsion Laboratory
California Institute of Technology
Pasadena CA, 91109

National Aeronautics and
Space Administration

JPL D-13280

Mars Global Surveyor Project

Mission Sequence Plan

Preliminary Version (MGS 542-407, September 1995)

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Mission Sequence Plan Contents

Mission Sequence Plan Contents

FIGURES

TABLES

1. Introduction

1.1 Purpose

The purpose of the Mission Sequence Plan is to describe a detailed sequencing strategy for the Mars Global Surveyor mission. The document will be used by the operations teams of the Mission Operations System (MOS), primarily the Mission Planner and the Sequencing Team, to create stored command sequences for operating the spacecraft in flight. These sequences will also be used before launch for testing of the spacecraft and the MOS.

1.2 Scope

The Mission Sequence Plan covers the use of stored command sequences on the spacecraft to accomplish the baseline Mars Global Surveyor mission, which is described in the Mars Global Surveyor Mission Plan (MGS 542-405). The baseline mission is the planned series of mission events that would proceed from launch to the end of the mission, without any failures that would affect the normal functioning of the spacecraft.

The initial spacecraft activities will be executed from two special stored command sequences generated by Lockheed Martin which are initiated autonomously by the flight software upon launch detection and detection of spacecraft separation from the Delta third stage, respectively. The activities contained in these sequences control the spacecraft from launch through upper stage separation, deployment of the solar arrays, DSN initial acquisition, and the transition into the inner cruise mode. Control of the spacecraft using the sequences defined in this document begins approximately two days after launch after the spacecraft has acquired the inner cruise mode.

This document is organized as follows:

Section 2 Provides overview of the sequencing strategy, defines the breakdown of the mission into separate sequences, identifies the mission critical sequences, describes the spacecraft blocks, gives definitions for some macro-blocks or “activities”, summarizes AACS and telecom usage throughout the mission, and describes the spacecraft launch timeline

Section 3 Provides descriptions for each of the cruise sequences, comprised of a description in text, a summary table, a state table, a timeline and guidelines and constraints.

Section 4 Provides similar descriptions for the orbit insertion phase sequences . Also provides a description of the specialized sequencing strategy to be used for the aerobraking period of the orbit insertion phase.

Section 5 Provides overview of the sequencing strategy for the mapping phase. Due to the length of the mapping sequences and dependence on actual DSN allocations, it is not possible to provide the same level of detail as described for each of the cruise and orbit insertion phase sequences. Only representative portions for the mapping phase are described.

Detailed requirements have not currently been defined for the relay support phase of the mission, which lasts for approximately three years upon completion of the mapping phase. Consequently sequences have not been defined for this phase of the mission.

The information contained in Sections 3 through 5, as described above, is intended to provide a starting point for the Mission Planner and the Sequencing Team to develop the sequences in-flight. As such, complete details such as block and command input parameters are not provided for the non-critical flight sequences. For the identified critical flight sequences, however, the actual Spacecraft Activity Sequence Files, SASFs, containing the detailed block and command input parameters will be included as Appendices in the December 1995 update of this document. These critical sequences are intended to be generated and tested on the spacecraft during system level and MOS compatibility testing prior to launch.

In general, the planned operations of the spacecraft are consistent with the requirements of the spacecraft contract. In some cases, where spacecraft capabilities in excess of the minimum requirements have been documented during the critical design reviews, the Mission Sequence Plan describes plans for payload operations beyond the minimum requirements.

1.3 Reference Documents

The following documents provide guidelines for the content of the Mission Sequence Plan:

Lockheed Martin Documents	**Document No.**	**Revision/ Issue Date**
Block Dictionary	542-SE-009	Draft/ June 1995
Command Dictionary	542-SE-012	Draft/ June 1995
Flight Rules	542-SE-013	Draft/ April 1995
Launch Event Timeline	542-SE-014	Draft/ August 1995

JPL Documents	**Document No.**	**Revision/ Issue Date**
Mission Plan	542-405	Final/ October 1995
Flight and Mission Rules	542-409 (Vol 10)	Draft/ April 1995

1.4 Update Schedule

Updates for the Mission Sequence Plan will occur on the following schedule as set by the MGS Mission Manager:

Preliminary	September 1995
Update	December 1995
Final	August 1996

1.5 Questions or Comments?

General comments, corrections, suggestions, or inquires about this document may be submitted to the author:

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2. Mission Sequences

2.1 Sequencing Overview

The Mars Global Surveyor mission spans five distinct mission phases: launch, cruise, orbit insertion, mapping, and the relay support phase. After liftoff, the spacecraft activities in the launch phase are controlled by two Lockheed Martin generated flight software initiated stored sequences, triggered from detection of liftoff and separation from the Delta third stage, respectively. These sequences control the post-separation despin, deployment of the solar arrays, DSN initial acquisition and acquisition of the inner cruise mode.

The cruise phase and orbit insertion phase (excluding the aerobraking period) have been divided into sequences based on the required spacecraft activities and on the ground resources required to generate the sequences. During the cruise phase, the ideal sequence duration is 35 days. This is to accommodate a 56-day DSN predict schedule and a three week sequence development cycle. Orbit insertion sequences (excluding the period of aerobraking) are typically shorter in duration, varying from 3 days to as long as approximately 44 days. This is to limit to one the number of major maneuvers in each sequence. Subsection 2.2 gives the exact sequence durations for the cruise and orbit insertion sequences. Many of the sequences have been further divided into loads that will be uplinked to the spacecraft separately. Cruise and orbit insertion sequences are made up of one to four loads. Load boundaries represent natural break points between activities in a sequence. In most cases, a sequence load separates out activities which are contingent upon execution of the previous loads, or activities that may or may not be executed.

During the three months of aerobraking a specialized sequencing strategy is used, tailored for the repetitive but time critical orbit to orbit commanding requirements of this period. This strategy is described in Section 4.

During the mapping phase, due to the repetitive nature of the science data collection and return and the utilization of an autonomous spacecraft eclipse detection and sequence initiation capability (AEM) it is desirable and possible to generate longer duration sequences. It is currently planned for average mapping sequence durations of six weeks. In order to achieve this, the three week sequence development process needs to be decreased and/or the DSN predict schedule increased from 56 days

No attempt has been made to calculate sequence memory word usage in the MSP. The amount of sequence memory available for MGS equals and will probably exceed that which was available for sequences on Mars Observer. Sequence sizes for MGS also appear to be smaller than those required for Mars Observer for which the allocated sequence memory was more than sufficient. Therefore it is assumed in this plan that sequencing memory size will not be a contraint for MGS.

No specific DSN allocations are available until the sequence generation process. Hence, the MSP typically shows only DSN view periods, and assumes all activities are on prime shift.

All times listed in the MSP are the UTC time of the event as received on the Earth (UTC ERT) in order to synchronize the downlink with ground activities. The dates listed may be either injection relative, MOI relative, or a fixed calendar date depending on the sequence.

2.2 Summary of Mission Sequences

The cruise phase has been divided into 11 sequences, designated C1 to C11, as shown in Table 2.2-1. The sequence boundaries have been set to group similar activities together and isolate certain critical events. The sequence durations are between 12 days and 35 days, and two sequences have variable duration, depending on the launch date. The first three sequences are timed from launch (L) and the last four are timed from MOI. In between, four sequences have boundaries on fixed calendar dates, resulting from the fixed date for outer cruise transition (1/6/97). The ideal sequence duration in cruise is 35 days, determined by the 8 week DSN allocation schedule minus 3 weeks for the length of the sequence development process.

Seven sequences have been defined for the orbit insertion phase, and these are shown in Table 2.2-2. These are designated T1 to T7, where T stands for the transition period from the cruise trajectory to the mapping orbit. Most of these sequences are short, typically 3 to 44 days to isolate the orbit insertion maneuvers into different sequences. Two of the sequences are of variable duration, depending on the date of MOI and the duration of aerobraking. The extended period between the end of T3 and the start of T4 represents the aerobraking portion of the orbit insertion phase. A specialized sequencing strategy is employed to handle the repetitive but time critical sequencing required during this time period, as described in Section 4.4.

The date of the start of mapping is fixed for the duration of the launch period to be March 15, 1998. The mapping phase is 687 days in duration and has been divided into 19 sequences designated M1 through M19, as shown in Table 2.2-3. The typical mapping sequence is 42 days in duration.

TABLE 2.2-1 CRUISE PHASE SEQUENCES

ID	Sequence Name	Duration (days)	Start	End	Loads	Major Events
C1	S/C Checkout and TCM1	16	L + 2*	L + 18	A B C D E F	Launch playbacks Propulsion system priming Regulator Checkout Full propulsion system pressurization TCM-1 Pressurant Isolation
C2	Post-Launch P/L Checkout	12	L + 18	L + 30		P/L Checkout
C3	MOC Bakeout	12 to 33	L + 30	1/6/97		MOC bakeout heater on, RS USO Tests, Telecom Tests Transition to Earth pointing by realtime ephemeris update 1/6/97
C4	Outer Cruise Transition	35	1/6/97**	2/10/97		Switch downlink to HGA, HGA calibration RS USO Tests MOC bakeout heater off, MOC focus check
C5	Early Outer Cruise	35	2/10/97**	3/17/97		RS USO Tests RS Tracking System Calibration MAG Calibration Window
C6	TCM-2	28	3/17/97**	4/14/97	A B	TCM-2 at L+135 days (3/19/97 for open of launch period, 4/9/97 for close)
C7	TCM-3	25 to 36	4/14/97**	MOI-125	A*** B***	TCM-3 at L+165 days (4/18/97 for open of launch period, 5/9/97 for close) RS USO Tests
C8	Outer Cruise I	35	MOI-125	MOI-90		MOC Mars Approach Image at MOI-120 days
C9	Outer Cruise II	35	MOI-90	MOI-55		MOC Mars Approach Images at MOI-90 and MOI-60 days
C10	Outer Cruise III	35	MOI-55	MOI-20		MOC Mars Approach Image at MOI-30 days
C11	TCM-4	13	MOI-20	MOI-7		TCM-4 at MOI-20 days Window for Contingency TCM-4 at MOI-10 days

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* Launch (L) period is from Nov 5, 1996 through Nov 25, 1996, corresponding to a Mars arrival period from Sept 11, 1997 through Sept 22, 1997

** Fixed sequence start dates are Mondays.

*** TCM-3 placed in A load for first few launch days and in B load for remainder of launch period.

TABLE 2.2-2 ORBIT INSERTION PHASE SEQUENCES

ID	Sequence Name	Duration (days)	Start	End	Loads	Major Events
T1	MOI	9	MOI-7*	MOI+2	A B C	Regulator Checkout Full Propulsion System Repressurization MOI
T2	Post Capture Checkout	7	MOI+2	MOI+9		P/L Activation Aerobrake Drag Pass Rehearsal
T3	AB1	3	MOI+9	MOI+12		AB1 Maneuver
	AEROBRAKING (SPECIALIZED REPETITIVE SEQUENCING)					
T4	ABX	26 (open) 37 (close)	MOI+132 (open) MOI+113 (close)	MOI+159 (open) MOI+151 (close)		ABX maneuver Enable AEM for TWTA cycling Gravity Calibration
T5	TMO	12	MOI+159 (open) MOI+151 (close)	MOI+171 (open) MOI+163 (close)	A B	TMO Maneuver MOC Focus Check
T6	OTM-1	3	MOI+171 (open) MOI+163 (close)	MOI+174 (open) MOI+166 (close)	A	OTM-1Maneuver
T7	Mapping Transition	12 (open) 10 (close)	MOI+174 (open) MOI+166 (close)	MOI+186 (open) MOI+176 (close)	A B C	NTO Isolation, HGA Deployment and Calibration Transition to nadir pointing P/L Activation and mapping rehearsal

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* MOI or Mars arrival period is from Sept 11, 1997 through Sept 22, 1997.

TABLE 2.2-3 MAPPING PHASE SEQUENCES

ID	Duration (days)	Start	End	Data Rate (ksps) (rec/pb/rt)	Major Events
M1	28	3/15/98	4/12/98	4/21/40	
M2	22	4/12/98	5/4/98	4/21/40	
M3	17	5/4/98	5/21/98	250 bps/4 ksps	Solar Conjunction
M4	39	5/21/98	6/29/98	4/21/40	DSN required to be one-way during S&E-2 passes
M5	42	6/29/98	8/10/98	4/21/40	Science Campaign B (6/29 through 7/6) DSN required to be one-way during S&E-2 passes (except for Madrid/Goldstone passes from 8/2 to 8/10)
M6	42	8/10/98	9/21/98	4/21/40	DSN required to be one-way during S&E-2 passes (except for Madrid/Goldstone passes from 8/10 to 8/30)
M7	35	9/21/98	10/26/98	8/42/40	
M8	35	10/26/98	11/30/98	8/42/40	Science Campaign C (10/26 through 11/2)
M9	28	11/30/98	12/28/98	8/42/40	Aphelion (12/12/98)
M10	35	12/28/98	2/1/99	16/85/40	Science Campaign D1 (1/5 through 1/12) Science Campaign D2 (1/20 through 1/27)
M11	42	2/1/99	3/15/99	16/85/40	Science Campaign D3 (2/3 through 2/10) Science Campaign D4 (2/18 through 2/25)
M12	42	3/15/99	4/26/99	16/85/40	
M13	42	4/26/99	6/7/99	16/85/40	Science Campaign E (5/3 through 5/10)
M14	42	6/7/99	7/19/99	16/85/40	No Earth occultations beginning 6/19
M15	42	7/19/99	8/30/99	16/85/40	
M16	42	8/30/99	10/11/99	16/85/40	Science Campaign F (9/29 through 10/4)
M17	28	10/11/99	11/8/99	16/85/40	
M18	42	11/8/99	12/20/99	8/42/40	Science Campaign G (12/13 through 12/20) Earth Occultations resume 11/25
M19	42	12/20/99	1/31/2000	8/42/40	

2.3 Block Descriptions

This document is intended to serve as a handbook for the construction of the spacecraft sequences from which the mission will be built. In a similar manner, each of these sequences will be built from command blocks, hereafter referred to simply as blocks. Mars Global Surveyor blocks are descriptions of spacecraft activities as represented in the ground software. Blocks are logical groupings of the commands required to perform a specific activity and are intended to be generalized and reusable, with parameters for timing or hardware selection that can be modified for specific applications. Because of this design philosophy, there are many instances during the mission where the spacecraft will be executing more than one block at the same time. This is achievable because of the onboard implementation of the blocks in the form of scripts.

2.3.1 Script Implementation

A script can be thought of as a command macro; a series of commands and command data words issued in order and separated by some time interval, Δt. There is some limited flexibility on the usage of these scripts, since each script can be called with certain arguments that are updated at the time of execution. Each of these arguments provides a new value of one of the following: one of the commands to be issued by the script, one of the data words of one of these commands, or the relative Δt between any two commands.

To cause the commands within a script to be issued, the script must be activated. After the script is activated, it is placed on the active script list and as the time tag for each command expires, the flight software will issue that command. The maximum number of scripts allowed to be active at any time is defined by the ground when the script buffer memory is initialized. Each spacecraft block is uplinked as one or more scripts. Furthermore, for commonly used blocks, certain "utility" scripts may be left onboard the spacecraft from one memory load to the next. This will reduce uplink traffic and may also reduce the amount of memory required to execute any given load by reusing scripts simply by updating parameters. Memory usage may also be conserved by identifying scripts that are common to one or more blocks, allowing these blocks to effectively "share" a common subroutine.

2.3.2 Spacecraft Blocks

Twenty-one blocks have currently been identified for use onboard Mars Global Surveyor. These are listed in Table 2.3-1. Some are used only once during the mission while others will be used daily for most of the mapping phase. The functionality of each of the blocks is briefly summarized below, and an indication of the frequency of its use is also included. A more detailed description of the activities and commands associated with each of these blocks is provided in the Mars Global Surveyor Block Dictionary.

The following seven blocks are used to activate or deactivate various payload instruments. **PDS** is used to activate / deactivate the Payload Data Subsystem. **ER** is used for the Electron Reflectometer, **MAG** for the Magnetometer, **MR** for the Mars Relay, **MOC** for the Mars Orbiter Camera, **MOLA** for the Mars Orbiter Laser Altimeter, and the **TES** block for the Thermal Emission Spectrometer. Additionally, due to the ER being mounted on the solar array, the **ER_SA_MODE** block is used to provide updates to the solar array motion modelling parameters during mapping.

TABLE 2.3-1 SPACECRAFT BLOCKS

Block Name	Mission Phase Applicability	Purpose
PRIMER	Cruise	Biprop Propulsion Priming
PRESSURE	Cruise / Orbit Insertion	Propulsion System Pressurization / Isolation
MNVR	Cruise / Orbit Insertion	Propulsion Maneuver s
AEROBRAKE	Orbit Insertion	Aerobraking Drag Pass
ABM	Orbit Insertion	Aerobraking Maneuvers
HGADPLY	Mapping	HGA Deployment
MAPFIG	Mapping	Mapping Acquisition
MAP_PB	Mapping	Mapping Communications
MAP_RT	Mapping	Mapping S&E-2 Communications
OTM	Mapping	Mapping Maneuvers
COMM	All	Real-time Communications
SSRMGR	All	Solid State Recorder Manager
MANLOAD	All	Maneuver Parameter Load
ER	All	ER Activation / Deactivation
ER_SA_MOD	Mapping	ER Solar Array Model Configuration
MAG	All	MAG Activation / Deactivation
MOC	All	MOC Activation / Deactivation
MOLA	All	MOLA Activation / Deactivation
MR	All	MR Activation / Deactivation
PDS	All	PDS Activation / Deactivation
TES	All	TES Activation / Deactivation

The **COMM** block is used primarily during cruise, to manage spacecraft realtime downlink communications. Its primary function is to configure the telemetry modulation that will be provided to the MOT from the Cross-Strap Unit (XSU), for downlink over the HGA or LGA as selected. The COMM block can configure the XSU to route realtime telemetry to the MOT from either the Engineering Data Formatter (EDF) or the Payload Data Subsystem (PDS). The block provides a full selectability to choose the rate at which any of these devices generates data, and also provides the capability to choose a modulation index appropriate to the downlink data rate. The COMM block additionally is used to power on and off the RF Power Amplifiers (TWTAs) as required during cruise.

SSRMGR is the command block that is used for all Solid State Recorder (SSR) functions except playback in mapping, for which the MAP_PB block is used. The SSR functions of SSRMGR are record and playback. The record command specifies the source of the data stream (EDF or PDS). The block can command either of these units to any of their data rates and formats as it begins recording. Each of the SSR functions is directed at one of the four recorders. SSRMGR will be used for continuous recording during cruise for anomaly resolution as well as for recording and playing back critical spacecraft events. During mapping SSRMGR is utilized for continuous recording of science telemetry.

Before the first maneuver after launch, the propulsion system must be prepared using the **PRIMER** and **PRESSURE** blocks. The PRIMER block is used to evacuate the lower propulsion lines, between the tanks and the main engine, and finally to open the latch valves which will wet the lower propulsion lines with fuel or oxidizer, as appropriate. This block must be verified before using the PRESSURE block. The PRESSURE block is used to manage the opening and closing of various propulsion system pyro valves in order to pressurize and isolate various branches of the system as required throughout the mission. The primary options are to pressurize the system for the first time prior to TCM-1, to isolate the high pressure helium after TCM-1 and to repressurize the system prior to MOI.

The **MANLOAD** block is used to load the maneuver parameters into the appropriate region of the AACS flight software prior to executing the MNVR or OTM blocks to perform a propulsive maneuver. An example of the maneuver parameters loaded by MANLOAD are required ΔV, minimum and maximum burn times, and desired burn attitude.

MNVR is the maneuver block that performs the set-up and execution of main engine (bipropellant) or thruster (monopropellant) propulsion maneuvers in cruise and orbit insertion (excluding the aerobraking corridor control maneuvers or ABMs which are executed with the ABM block). The block provides the option to select the desired maneuver type, either main engine or thruster, with a separate selection for the MOI maneuver. Selecting the MOI option enables enhanced fault-protection and abort/restart features, which are implemented in the flight software. The block also provides the option to perform the selected maneuver type as an inertially fixed burn or as a "pitchover" with the desired pitch rate and vector specified. The MOI option automatically selects the "pitchover" option.

The **ABM** block is used to perform the periapsis control corridor maneuvers during the aerobraking portion of the orbit insertion phase. The ABMs are executed as thruster maneuvers at apoapsis to either raise or lower the periapsis altitude as required. The ABM block is nearly identical to the MNVR block, but has several additional built in options designed to facilitate the time critical sequencing requirements of these maneuvers. The first option begins recording high rate engineering telemetry on a selected recorder throughout the maneuver event and plays the data back upon completion of the burn when the spacecraft has reacquired the normal Earth pointing cruise attitude. The ABM block also contains the commands normally executed in the MANLOAD block for loading the required maneuver control flight software parameters.

The **AEROBRAKE** block is executed, as the name suggests, each orbit during the aerobraking portion of the orbit insertion phase to configure and orient the spacecraft for entry into the atmosphere, centered around periapsis. Both the AEROBRAKE and ABM blocks are discussed in greater detail in Section 4.4.

The deployment of the spacecraft bus from the cruise configuration to the mapping configuration is accomplished with two blocks, the **HGADPLY** and **MAPFIG** blocks. The HGADPLY block will deploy and align the HGA into its Mapping configuration. It should be noted that the position of the HGA in the Mapping configuration precludes the further use of the bipropellant system without irreparable damage to the HGA. After the HGA deployment has been verified, the MAPFIG block will do the final mapping configuration. The MAPFIG block will acquire an attitude lock on Mars using the Mars Horizon Sensor Assembly (MHSA) upon which the transition will be autonomously made to the Mars nadir-pointed primary attitude mode. The block also configures the SA GDEs and the HGA GDE for autonomous tracking of the sun and Earth, respectively, during mapping.

During the mapping mission, the daily playback of recorded science data will be accomplished using the **MAP_PB** block. A block very similar to MAP_PB, called **MAP_RT**, is used in a similar manner for realtime science data return in the 40-ksps S&E-2 format, approximately every third day. Detailed descriptions for both of these blocks is provided in Section 5.

The **OTM** block is used throughout the mapping phase to perform the orbit trim maneuvers. The block is very similar to the thruster selection option of the MNVR block. The major difference between the two blocks is in the post burn configuration, in which the OTM block commands the spacecraft back to the mapping configuration, as opposed to the cruise configuration.

2.4 Activity Descriptions

When patterns of block and/or command calls are commonly repeated, the ground will be able to define a macro of these calls to expedite the sequence generation process. These groupings are called "Activities." In the development of the Mission Sequence Plan, a few promising candidates for activities have been identified. These activities are described below and used later in the document as a type of shorthand representation of the events described here. Athough they are not available in the preliminary MSP, the update to preliminary MSP in December 1995 will include a listing of the initial and final conditions of the spacecraft, along with the parameters required for the expansion of the activity, and finally, a listing of the block and/or commands generated by the activity, including the relationship between activity parameters and block parameters, if applicable.

2.4.1 CRS_REC Activity

The CRS_REC activity is used throughout cruise to provide continual recording for contingency purposes to capture spacecraft telemetry up to the point of an anomaly when continuous DSN coverage is not available due to scheduling frequency or outages. The contingency recording strategy uses two recorders alternating every four days, assuming a normal record rate of 2000 bps. In order to minimize the required playback duration in the event of an anomaly, the recorder memory is divided into eight partitions, with each partition holding 12 hours of 2000 bps engineering telemetry. Playing back the telemetry at the 8000 bps rate ensures that data on a single partition can be returned within 3 hours. Fault protection telemetry, specifically the contents of the audit queue, will allow the ground to establish the time of the anomaly and thus determine which recorder and partitions should be played back.

2.4.2 MAP_REC Activity

The MAP_REC activity is used throughout mapping to provide continual science data recording. As described in further detail in Section 5.0, the mapping science data collection and return strategy consists of recording science data for 24 hours and returning it during a daily 10 hour DSN pass. The playback of the data is performed over four orbits or in four 67.5 minute segments. Each 67.5 minute segment corresponds to 6 hours of recording. Because the recorders to not possess a “rewind” capability, in order to ensure that no data is lost as the spacecraft exits occultation during DSN station telemetry lockup, a second recorder is used to record the next 6 hour segment with a ten minute overlap from the end of the previous record segment. Therefore a 24 hour record period consists of four 6 hour segments on alternating recorders, with ten minute overlaps between each record segment.

2.4.3 MOC_CAL Activity

The MOC_CAL activity will be used throughout the cruise and orbit insertion phases to orient the spacecraft to allow the MOC to acquire star images as part of the instrument focus check strategy and to acquire images of Mars upon approach to the planet. This activity takes advantage of the spacecraft attitude control mode called Inertial Slew/Hold (ISH). In the ISH mode, the spacecraft first turns to a specified inertial attitude and then, from that attitude, begins a slew at a constant angular motion about a specified inertial direction. In order for the MOC to acquire images it is required that the spacecraft rotate about the +Y axis. In the mapping attitude control modes the spacecraft normally rotates about the +Y axis as it moves around the planet. However, in the normal cruise ANS mode, the spacecraft rotates about the +X axis instead. Therefore the spacecraft is commanded to an initial inertial attitude using the ISH mode

2.4.4 PAT_TEST Activity

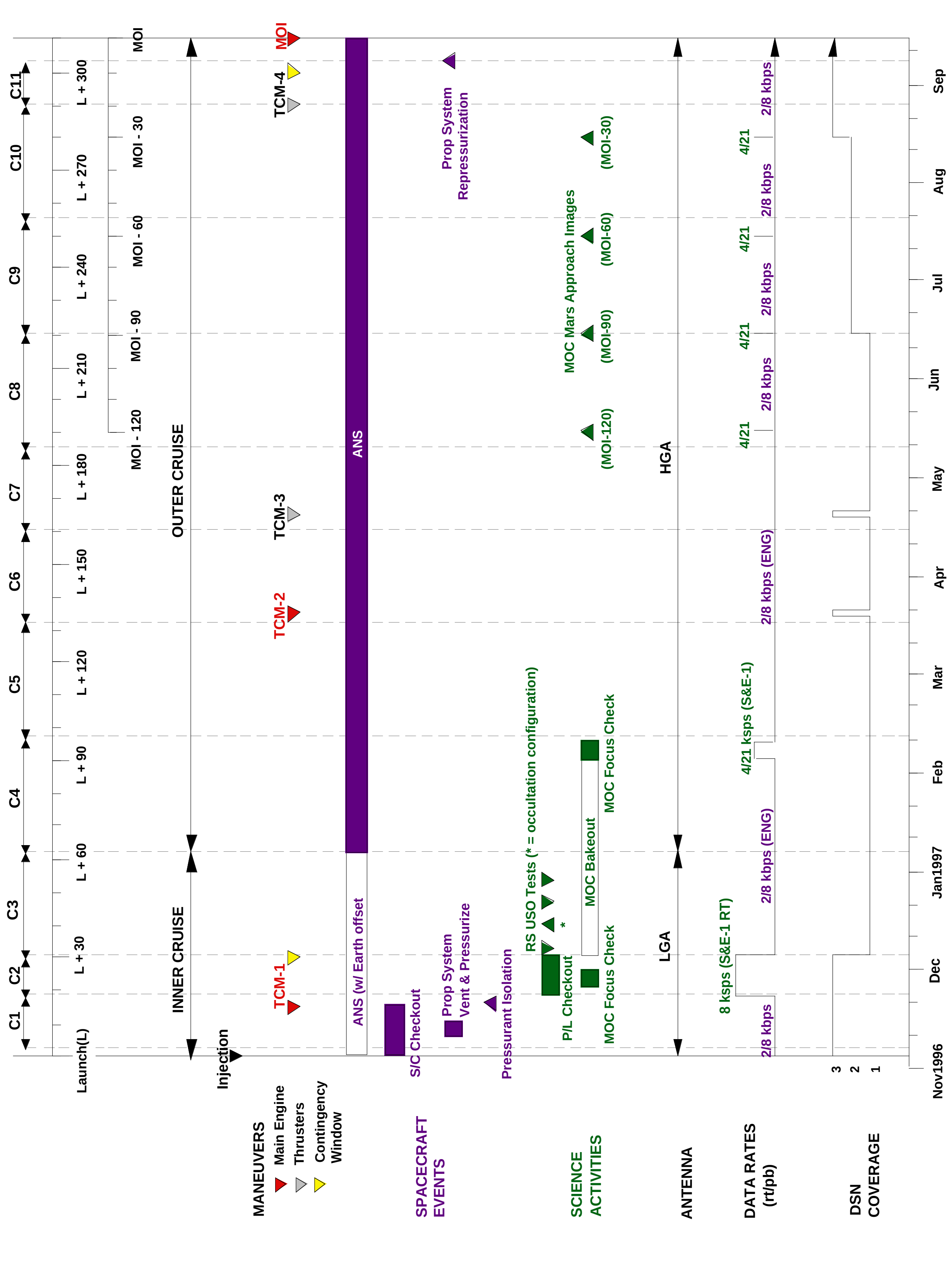
The PAT_TEST activity will be used during cruise to map the HGA pattern. Similar to the MOC_CAL activity, the PAT_TEST also utilizes the ISH attitude control mode. The HGA mechanical boresight is nominally aligned with the spacecraft +X body axis. During outer cruise, both of these directions are pointed along the line from the spacecraft to the earth. The PAT_TEST activity will place this axis some specified cone angle, α (approximately 0.8°, corresponding to the 3 db margin), off of the earth line. Next, the spacecraft will begin to rotate about the +Y axis, through an angle described by θ. As the spacecraft rotates about this axis, varying θ from 0° to 360°, the line-of-sight between the earth and the HGA will map out a circle α degrees from the mechanical boresight. A three dimension gain map can thus be produced to recreate gain as a function of cone (α) and clock (θ) angles. Any offset of the electrical boresight from the mechanical can also be deduced from this map.

3. Cruise Phase

3.1 Sequencing Overview

Figure 3.1-1 shows how the cruise phase sequences overlay the mission phase timeline. The critical sequences defined for this phase are the C1 (Post-Launch Spacecraft Checkout and TCM1) sequence and the C2 (Payload Checkout) sequence. Both summary level and detailed sequence information is provided in this section for these two sequences. The actual Spacecraft Activity Sequence Files (SASF), for these sequences, containing the detailed block and command parameters, will be provided in Appendices A and B respectively, for the December 1995 update to this document. The remaining cruise sequences (C3 through C11) are left as TBD in the preliminary version of the MSP. Included in the final version of the MSP will be summary level descriptions and timelines of these sequences.

Figure 3.1-1 Cruise Phase Timeline



3.2 C1 Sequence Description

The C1 Sequence is the first sequence loaded on the spacecraft and covers the period from Launch (L) to L + 18 days. Included in this sequence are the configuration of the MOTs, playbacks from the SSRs of the launch events, propulsion system priming and pressurization, TCM1, and post TCM1 pressurant isolation. The critical events in this sequence have been placed into six separate loads, designated A through F, in order to allow assessment time by the ground prior to the uplink window of the next load.

Load A Launch Playbacks

The first load, Load A, begins execution at L+2 days. The first event commanded by the load is the configuration of the MOTs for cruise operations. Specifically ranging is turned on and the two-way coherent mode enabled. Additionally the USO is enabled as the downlink frequency source when the spacecraft MOT is in one-way noncoherent mode. Note that these commands may eventually be initialized on the launch pad prior to launch. However, they will be left in the C1 A load as a backup or as primary in the event the intial launch configuration does not contain these commands.

After the MOT configuration, the sequence load next commands the playback of the engineering telemetry recorded on SSR recorders 1A and 2A during the launch and spacecraft separation sequences, using the SSRMGR block. After each of the playbacks, the COMM block is used to regain 2000 bps engineering realtime downlink. Additionally, Load A initiates continual contingency recording of the 2000 bps engineering telemetry, alternating between SSR recorders 1B and 2B every four days (refer to the cruise contingency record activity defined in Section 2.4.1. Finally, Load A configures the MOT to enable ranging.

Load B Propulsion System Priming

Load B1 begins execution at L+6 days to vent and wet the bipropellant lines in preparation for pressurizing the propulsion system. The PRIMER block is used to accomplish this activity. The main engine valves are opened for 30 seconds to vent the blanket helium gas in the main engine lines to space. After closing the main engine valves, Latch Valves (LV) 4 and 5 are opened up to allow the fuel and oxidizer to fill the lines down to the engine valves. Once the main engine lines have been wet, the system is ready to be pressurized. In order to prevent against a main engine valve leak, LVs 4 and 5 are closed upon completion of the priming event.

Load C Propulsion System Initial Pressurization and Regulator Checkout

Load C is uplinked at L+8 days, upon verification of the priming event in the previous load. It contains the events required to perform a partial propulsion system pressurization, allowing the ground to determine if the primary regulator has failed wide open. The PRESSURE block is used to pressurize the system, with the option selected to open normally closed Pyro Valve (PV) 6 to allow the flow of high pressure helium gas to bring the primary pressure regulator on-line. In order to protect against a failed open regulator, the sequence has commands to close high pressure LV 1 after a small period of time (~10 seconds).

Load D Propulsion System Full Pressurization

Upon verification that the primary regulator has not failed open after the inital pressurization performed in Load C, Load D is uplinked to the spacecraft at L+10 days. The load contains the commands required to reopen LV1, allowing the system to be completely pressurized in preparation for TCM1. Additionally overpressure fault protection is enabled, to allow autonomous protection against a partial regulator leak.

Load E TCM1

Load E is uplinked to the spacecraft at L+15 days and contains the TCM1 maneuver events. Six hours prior to the maneuver, the MANLOAD block is executed from the sequence to load the necessary flight software maneuver control parameters into memory. The MNVR block is used to perform the TCM1 burn, with the main engine burn option selected. The burn attitude will be selected to maximize communications over the LGA at 2000 bps.

Load F Pressurant Isolation

After allowing two days to verify the execution of TCM1, Load F is uplinked to the spacecraft to isolate the helium pressurant. The PRESSURE block is used to close normally open PV 5, isolating the helium pressurant from the regulator. Additional commands in the load will also close LV 1 to further ensure isolation of the helium pressurant. Once the helium tank has been isolated, autonomous overpressure fault protection is disabled. If TCM1 fails to execute or is aborted, requiring a contingency TCM1 at L+30 days, Load F will not be uplinked to the spacecraft and the system will remain pressurized with overpressure fault protection enabled until completion of the TCM-1 contingency maneuver.

Table 3.2-1 C1 Sequence Summary

Sequence Name: Spacecraft Post-Launch Checkout and TCM1 Sequence

Mission Phase: Inner Cruise

Start Date: 16:00:00 L+2 days (UTC ERT)

End Date: 16:00:00 L+18 days (UTC ERT)

Duration: 16 days

DSN Coverage: Continuous

Uplink Windows:

Load A:	04:00:00	L+2	to	12:00:00	L+2 days
Load B:	04:00:00	L+6	to	12:00:00	L+6 days
Load C:	04:00:00	L+8	to	12:00:00	L+8 days
Load D:	04:00:00	L+10	to	12:00:00	L+10 days
Load E:	04:00:00	L+15	to	12:00:00	L+15 days
Load F:	04:00:00	L+17	to	12:00:00	L+17 days

Load Boundaries:

Load A:	16:00:00	L+2	to	16:00:00	L+6 days
Load B:	16:00:00	L+6	to	16:00:00	L+8 days
Load C:	16:00:00	L+8	to	16:00:00	L+10 days
Load D:	16:00:00	L+10	to	16:00:00	L+15 days
Load E:	16:00:00	L+15	to	16:00:00	L+17 days
Load F:	16:00:00	L+17	to	16:00:00	L+18 days

	Load A	Load B	Load C	Load D	Load E	Load F
Duration (days):	4	2	2	5	2	1
Major Activities:	Launch Playbacks	Vent & Wet Main Engine Lines	Regulator Checkout	Propulsion System Pressurization	TCM1	Pressurant Isolation
Blocks/ Activities Used:	SSRMGR (4) COMM (4) CRS_REC	PRIMER CRS_REC	PRESSURE	CRS_REC (2)	MNVR	PRESSURE
Realtime Uploads:				Star Tables and Ephemeris Tables		

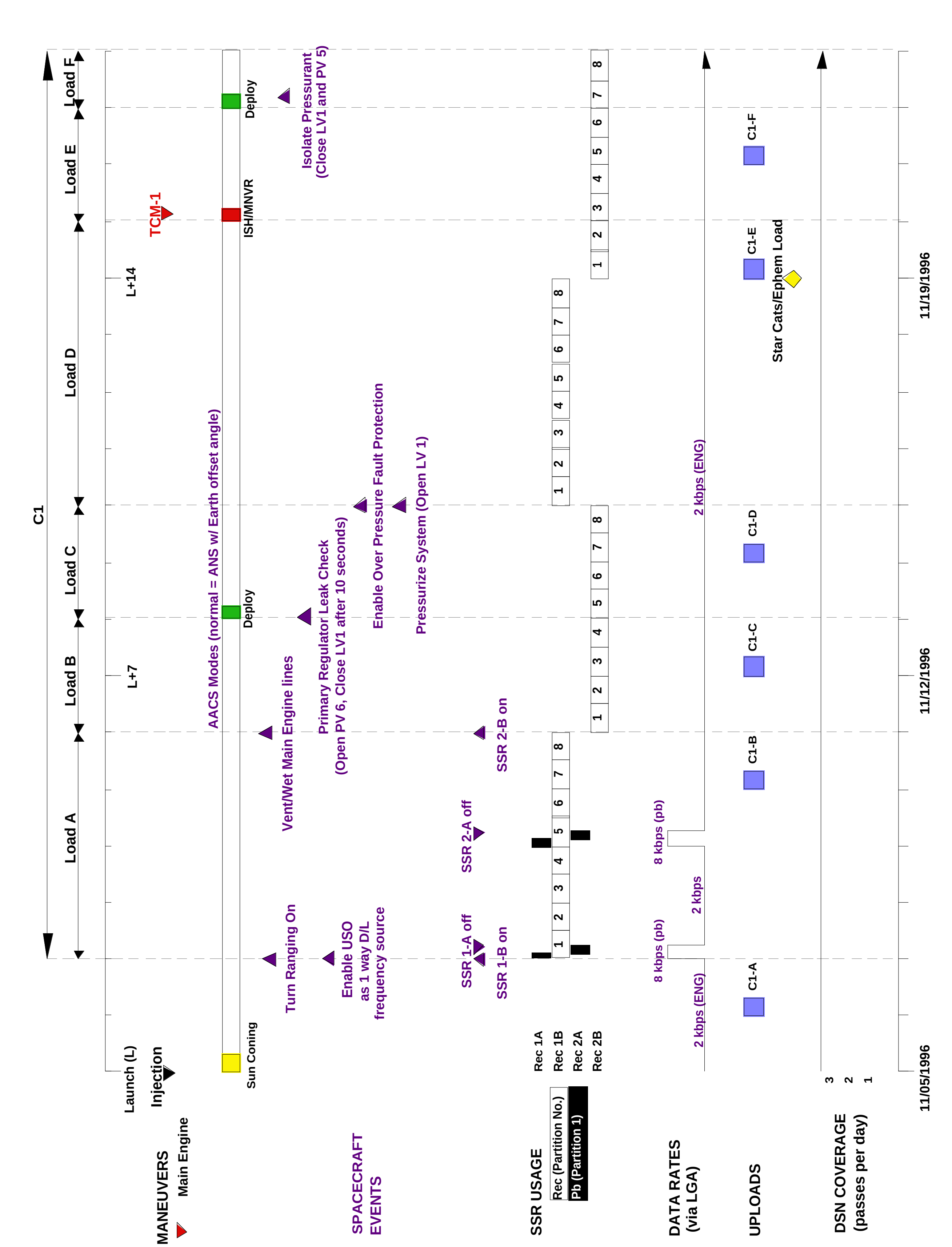
Table 3.2-2 C1 Sequence State Table

	Initial State	Transition States	Final State
Spacecraft Attitude	ANS	ISH / DEPLOY (Loads B & F) ISH / MNVR (Load E)	ANS
Antenna	LGA		LGA
CDU rate	125 bps		125 bps
Data Mode	ENG 2 kbps	PB 8 kbps (Load A)	ENG 2 kbps
EDF Mode	ENGINEERING		ENGINEERING
Modulation Index	72.4°	75.0° (Load A)	72.4°
Ranging Modulation	OFF	ON (Load A)	ON
Telemetry Modulation	ON		ON
Noncoherent Mode	OFF		OFF
USO	ON		ON
PDS	OFF		OFF
MAG	OFF		OFF
ER	OFF		OFF
MR	OFF		OFF
MOC	OFF		OFF
MOLA	OFF		OFF
TES	OFF		OFF
SSR recorder 1A	ON, STANDBY	PB (Load A)	OFF
SSR recorder 1B	OFF	ON, RECORD (Load B)	ON, STANDBY
SSR recorder 2A	ON, STANDBY	PB (Load A)	OFF
SSR recorder 2B	OFF	ON, RECORD (Load B)	ON, STANDBY

----- Special States -----

Propulsion System	Sealed	Primed, Pressurized	Pressurant Isolated

Figure 3.2-1 C1 Sequence Timeline



3.3 C2 Sequence Description

The C2 Sequence is the Payload checkout sequence and covers the period from L+18 to L+30 days. This is the first time the instruments will be powered on in the mission. The checkout is to verify the instruments survived launch and are operating properly. The sequence begins on L+18 days with the turn on of the PDS using the block of the same name. The PDS RAM (28 kbytes) is next uploaded in realtime. After loading the RAM, the PDS memory, both RAM and ROM, are redundantly readout. The PDS checkout occurs on the second day of the load, allowing time for a backup PDS RAM load if necessary. The PDS checkout involves the PDS stepping through its eight different data modes, spending 15 minutes at each one. For the realtime rates (RTL, RTM, RTH), the S&E-1 data is recorded on SSR recorder 1A and played back at 8 ksps after the completion of the PDS checkout. The data rate remains at 8 ksps for the remainder of the payload checkout, with the exception of the 3 hour MR checkout, when the data rate is dropped to 4 ksps. The COMM block is used to configure the various realtime rates, while the SSRMGR block is used to manage the record and playback events. Throughout the load the cruise contingency record activity is used to continuously record 8 ksps telemetry, alternating between recorders 1B and 2B every day.

On the third day of the load, the MAG instrument is turned on and the ER cover opened followed the next day by the ER power on and high voltage enable. The MAG and ER blocks, respectively are used to perform these events. The MAG/ER will collect calibration data for 9 days.

On L+21 days, the MOC is turned on with the MOC block. The MOC will stay on for 5 days in order to perform its Single Event Upset / Single Event Latchup test (SEU/SEL) and the pre bakeout focus check. The focus check is spread out over five days, so that each day four pictures of a selected star are taken at one of the five heater settings. Each day new instrument parameters (e.g., rim heater settings) are uplinked. For each of the five picture sessions, the spacecraft is commanded to the ISH mode to hold the target attitude while rotating about the +Y axis at a desired rate, in order to allow the MOC to sweep across the star. After each sweep, the incremental slew angle is reset and the events repeated until four images have been acquired, at which time the spacecraft is returned to the normal ANS cruise attitude. It is anticipated that star selected will allow an attitude for which continuous 8000 sps downlink over the LGA throughout the activity. The payload calibration activity, defined in Section 2.x, is used to command the required turns for the focus check.

During the last three hours of MOC operation, the MR is turned on for its checkout. Additionally, the MOC is commanded to receive MR data and the PDS, via the COMM block, is commanded to the MR data mode (S&E-1 4 ksps). The MR block is used to power on the instrument and step through each of its 16 control modes. Upon completion of the MR checkout, the MR and MOC are turned off with their respective activation/deactivation block.

On L+27 days, the TES is turned on, using the TES block, for a 24 hour inner cruise calibration. Several instrument commands are uplinked to the spacecraft during this test. At the end of the checkout, the TES block is executed again to power the instrument off. On L+28 days, radio science performs its first USO test, lasting two hours. This test requires commanding the MOT to non-coherent mode and enabling the USO as the downlink frequency source. Upon completion of the test the MOT is commanded back to coherent mode. This test should be performed when DSN elevation angles are greater than 30°. After the RS USO test, MOLA is turned on for its checkout which lasts three hours and will include realtime uplinks which will take less than two minutes. The last day of the C3-A load is I+29 days. The data rate is reduced to 2 kbps following the completion of the payload activities via the COMM block. The entire payload is turned off to provide enough power for the contingency TCM1.

Table 3.3-1 C2 Sequence Summary

Sequence Name: Payload Checkout Sequence

Mission Phase: Inner Cruise

Start Date: 16:00:00 L+18 days (UTC ERT)

End Date: 16:00:00 L+30 days (UTC ERT)

Duration: 12 days

DSN Coverage: Continuous

Uplink Windows: Load A: 04:00:00 L+18 to 12:00:00 L+18 days

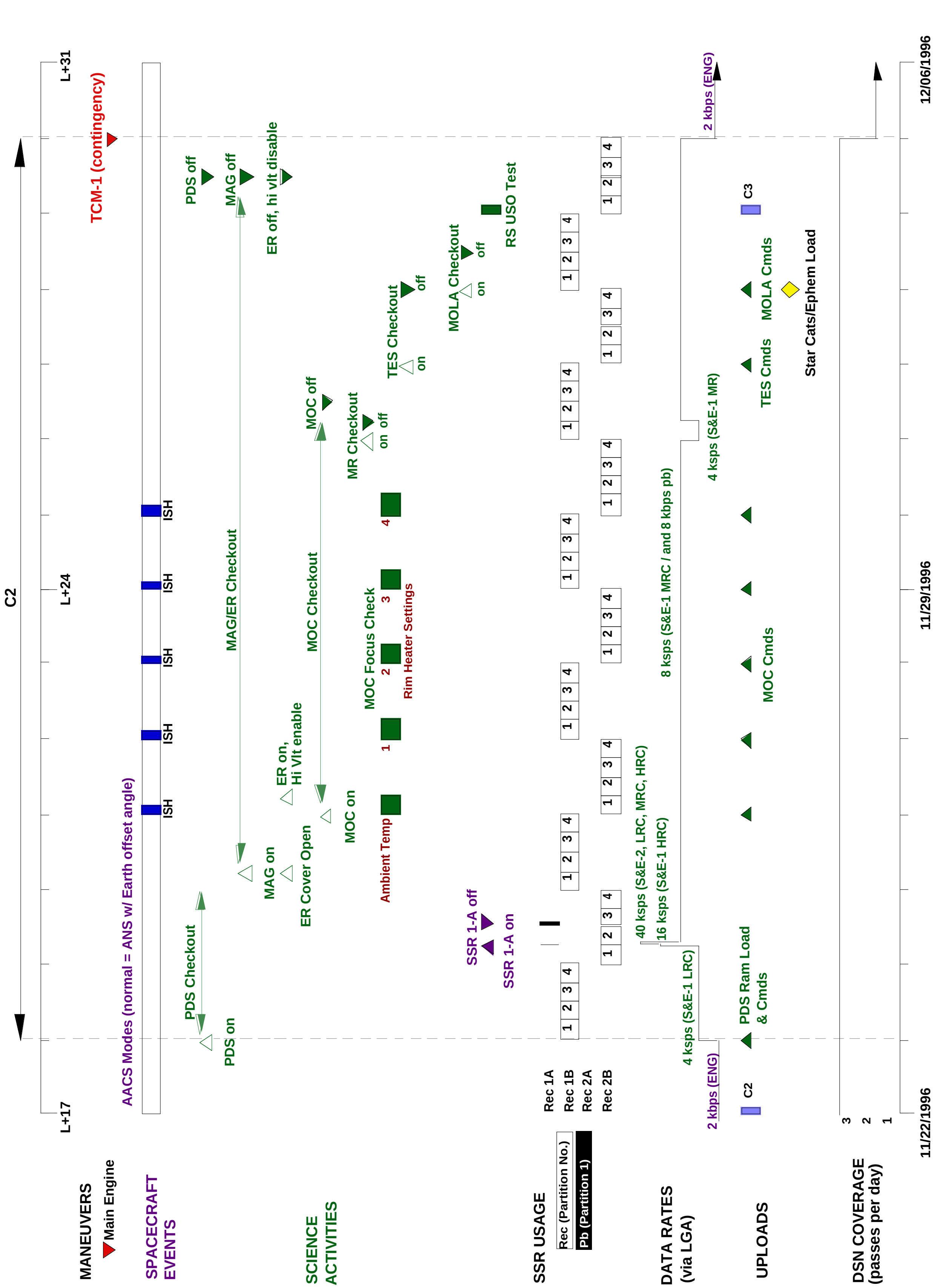
Load Boundaries: Load A: 16:00:00 L+18 to 16:00:00 L+30 days

Blocks / Activities Used:
SSRMGR (2)
COMM (7)
CRS_REC (12)
PDS (TBD)
MAG (2)
ER (2)
MOC (2)
MOC_CAL (5)
MR (TBD)
TES (2)
MOLA(2)

Table 3.3-2 C2 Sequence State Table

	Initial State	Transition States	Final State
Spacecraft Attitude	ANS	ISH	ANS
Antenna	LGA		LGA
CDU rate	125 bps		125 bps
Data Mode	ENG 2 kbps	S&E-1 4, 8, 16 ksps, S&E-2 40 ksps, PB 8 kbps	ENG 2 kbps
EDF Mode	ENGINEERING	MISSION	ENGINEERING
Modulation Index	72.4°	75.0°, 80.0°	72.4°
Ranging Modulation	ON		ON
Telemetry Modulation	ON		ON
Noncoherent Mode	OFF	ON	OFF
USO	ON		ON
PDS	OFF	ON	OFF
MAG	OFF	ON	OFF
ER	OFF	ON	OFF
MR	OFF	ON	OFF
MOC	OFF	ON	OFF
MOLA	OFF	ON	OFF
TES	OFF	ON	OFF
SSR recorder 1A	OFF	ON, REC (MOC Focus Check), PB (MOC Focus Check)	OFF
SSR recorder 1B	ON, STANDBY	ON, RECORD (Contingency)	ON, STANDBY
SSR recorder 2A	OFF		OFF
SSR recorder 2B	ON, STANDBY	ON, RECORD (Contingency)	ON, STANDBY

Figure 3.3-1 C2 Sequence Timeline



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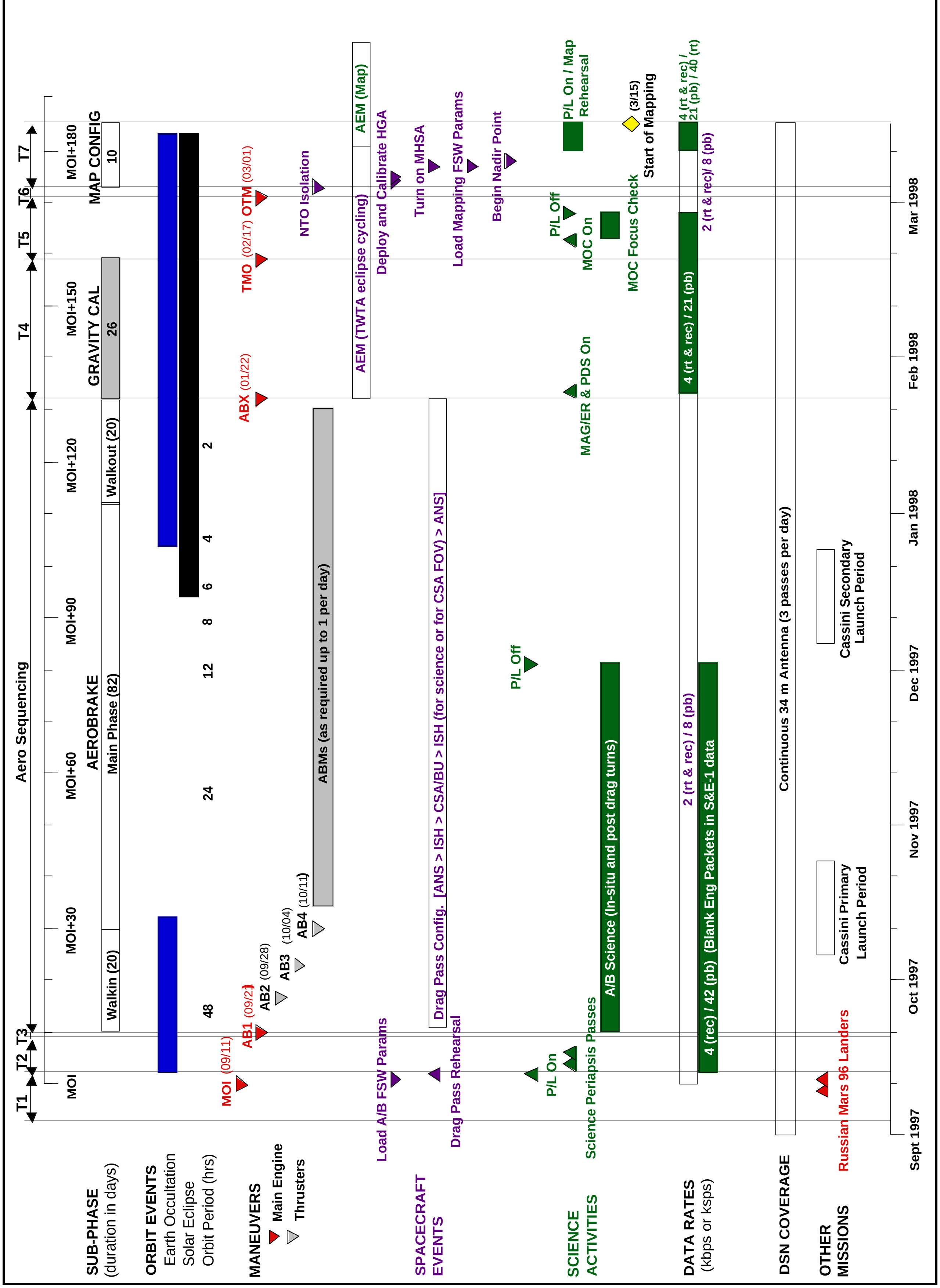
4. Orbit Insertion Phase

4.1 Sequencing Overview

Figure 4.1-1 shows how the orbit insertion sequences overlay the mission phase timeline. The critical sequences defined for this phase are the T1 (MOI) sequence and the T7 (Mapping Transition) sequence. Summary level and detailed sequence information is provided in this section and in Appendix A, respectively, for these sequences. The remaining orbit insertion sequences (T2 through T6) are left as TBD in the preliminary version of the MSP. Included in the final version of the MSP will be summary level descriptions only of these sequences. A separate subsection, 4.3 is devoted to the sequencing strategy to be employed during the aerobraking portion of orbit insertion.

Figure 4.1-1 Orbit Insertion Phase Timeline



4.2 T1 Sequence Description

The T1 sequence is the critical orbit insertion sequence and covers the period from MOI-7 days to MOI+2 days. Included in this sequence are the propulsion system repressurization and the Mars Orbit Insertion maneuver (MOI).

Load A Propulsion System Initial Repressurization and Regulator Checkout

Load A begins execution at MOI-7 days to prepare the spacecraft for MOI. The first event in the sequence is the disabling of safe mode entry due to software failures (refer to Section 4.2.1 for the safe mode disable strategy and rationale).

The load next begins the repressurization of the propulsion system. The PRESSURE block is used to open normally closed pyro valve 4 which isolates the regulator from the helium pressurant. The PRESSURE block switches the spacecraft to thruster control mode to maintain a desired inertial attitude as the pyro is fired. Consequently the HGA link will probably not be maintained in this mode. Therefore the load additionally switches from the HGA to the LGA for the brief duration of the pyro firing event. In order to maintain 2 kbps engineering telemetry recording on the SSR, the EDF is left in Engineering Mode and the ground will receive the carrier signal only over the LGA. In order to boost the strength of the carrier signal, telemetry modulation to the MOT is turned off. Upon returning to ANS, the load switches back to the HGA and reenables telemetry modulation to the MOT. Similar to the strategy employed during the initial system pressurization for TCM1, LV 1 is next reopened for a 10 second period in order to verify that the primary regulator is seated properly before proceeding with the full system repressurization.

Load A also initiates background contingency recording on SSR recorder 2B at MOI-5 days, covering the four day period up to MOI-1 day.

Load B Propulsion System Full Repressurization

Load B completes the pressurization of the propulsion system at MOI-5 days. Overpressure fault protection is reenabled and LV1 reopened to fully pressurize the propulsion system in preparation for the MOI maneuver. Refer to Section 4.2.1 for the strategy regarding execution of this load with respect to the MOI backup load.

Load C MOI

Load C is uplinked to the spacecraft at MOI-2 days and contains the final designed MOI maneuver sequence (refer to Section 4.2.1 for details about the MOI backup load strategy). At MOI-1 day, contingency recording is enabled on SSR recorder 1-B, covering the four day period through MOI+3 days. Six hours prior to MOI, the MANLOAD block is executed from the sequence to load the necessary flight software maneuver control parameters into memory. Four hours prior to MOI, contingency mode and the sun monitor ephemeris check disabled. At MOI-1 hour, recording of the MOI burn events is initiated on SSR recorder 2-B. The MNVR block is used to perform the capture maneuver, with the MOI option selected. Upon completion of the maneuver, the sequence load reenables safe mode, contingency mode and the sun monitor ephemeris check. Once the spacecraft has reacquired ANS upon completion of the burn and the transmitter turned back on for a realtime telemetry health and status check, playback of the recorded burn events on recorder 2-B is played back at 8 kbps using the SSRMGR block. A second redundant playback occurs 10 hours later.

4.2.1 Sequence Protection

Because there is only a single time critical window within which to accomplish MOI, special precautions as described below are taken to maximize the likelihood of the sequence executing successfully.

Safe Mode Disable

Entry into safe mode will terminate the T1 sequence. Although it is impossible to prevent hardware entries into safe mode, such as a spacecraft POR, software entries into safe mode can be inhibited. In order to protect the execution of the sequence, software entry into safe mode is disabled prior to MOI. The timing is determined from estimates of how long the flight team can recognize, remedy and recover from safe mode in time to perform MOI, while minimizing the period the spacecraft is without this protection. Currently this time is estimated to be MOI-7 days. As the operations team refines the safe mode recovery procedure this time will be updated accordingly.

Contingency Mode Disable

Similar to safe mode, contingency mode must also be disabled prior to MOI. Unlike safe mode however, the spacecraft can be configured to autonomously recover from contingency mode to a state from which MOI can be executed, without ground intervention. Upon entry into contingency mode a special pre-loaded ground defined command script is executed which commands the spacecraft from the contingency mode “sun comm power” attitude control state to the “sun star init” attitude control state. Both states are almost identical, with the critical exception that “sun star init” allows star identification. Once enough stars have been identified inertial reference is reestablished and MOI can be performed successfully. The maximum time required for the spacecraft to reestablish an attitude reference is approximately four hours. Therefore contingency mode is disabled at MOI-4 hours.

Several points should be noted with respect to the above strategy. First, since contingency mode is allowed to execute up to MOI-4 hours, the T1 sequence must be enabled for execution in contingency mode or it will be terminated upon contingency mode entry. Secondly, the autonomous recovery is not a complete recovery from contingency mode. The spacecraft remains in the “sun star init” attitude control mode, which is an allowed control state transition when the sequence commands to the ISH attitude control state to turn to the burn attitude. The uplink and downlink data rates are also left at their emergency rates. The ground can command the spacecraft back to ANS and regain normal HGA communications if there is sufficient time and it so desires. Finally an attitude sanity check, known as the sun monitor ephemeris check must also be disabled with contingency mode. This check is used to compare the ground predicted sun vector with the attitude control software propogated sun vector. If the two vectors miscompare by more than 2 degrees, the attitude control state is switched from ANS to “sun comm power” and contingency mode mode entered.

MOI Backup Load

At MOI-18 days, after completion of the TCM4 maneuver, all three loads of the T1 sequence are loaded on-board the spacecraft. All three loads are immediately activated and pending command execution at their required times. This will protect against the unlikely event of a ground or spacecraft failure which might prohibit uplink to the spacecraft for an extended period of time (e.g. the next LA natural disaster). At this point, no further action would be required by the ground to execute the critical MOI burn.

The B load containing the full propulsion system pressurization would normally, as was done with the initial system pressurization for TCM1, only be uplinked upon verification that the primary regulator is healthy after execution of the partial pressurization in Load A. However, consistent with the backup load strategy of having all the commands required to perform MOI on the spacecraft at MOI-18 days, this load will instead be terminated by the ground in the event of a large leak detected in the primary regulator. In the event that the primary regulator was determined to have a catastrophically large leak, the ground would be required to uplink an emergency command script to isolate the primary regulator and switch to the backup regulator, in order to proceed with the execution of MOI.

The C load uplinked at MOI-18 days, containing the MOI burn itself, is considered a backup load in that it will not contain the final designed MOI maneuver parameters. It will however, contain parameters with sufficient accuracy to place the spacecraft into orbit about Mars, in the event the final B load is prevented from being uplinked to the spacecraft. When the final B load is uplinked and received in whole by the spacecraft at MOI-2 days, the sequence will immediately terminate the Backup B load.

Table 4.2-1 T1 Sequence Summary

Sequence Name: Mars Orbit Insertion (MOI) Sequence

Mission Phase: Inner Cruise

Start Date: 16:00:00 MOI-7 days (UTC ERT)

End Date: 16:00:00 MOI+2 days (UTC ERT)

Duration: 9 days

DSN Coverage: Continuous

Uplink Windows:

Load A:	04:00:00	MOI-18	to	12:00:00	MOI-18 days
Load B:	04:00:00	MOI-18	to	12:00:00	MOI-18 days
Load C (backup):	04:00:00	MOI-18	to	12:00:00	MOI-18 days
Load C (final):	04:00:00	MOI-2	to	12:00:00	MOI-2 days

Load Boundaries:

Load A:	16:00:00	MOI-7	to	16:00:00	MOI-5
Load B:	16:00:00	MOI-5	to	16:00:00	MOI-2
Load C:	16:00:00	MOI-2	to	16:00:00	MOI+2

	Load A	Load B	Load C
Duration (days):	2	3	4
Major Activities:	Disable Safe Mode, Regulator Checkout	Propulsion System Re-Pressurization	Disable contingency mode, MOI
Blocks / Activities Used:	PRESSURE CRS_REC		MNVR SSRMGR (3) COMM (2)
Realtime Uploads:		Star Tables and Ephemeris Tables	

Special Sequence Load States: Contingency Mode Execution Bit enabled
Late Execution Inhibit Bit disabled
Proceed on Error Bit enabled

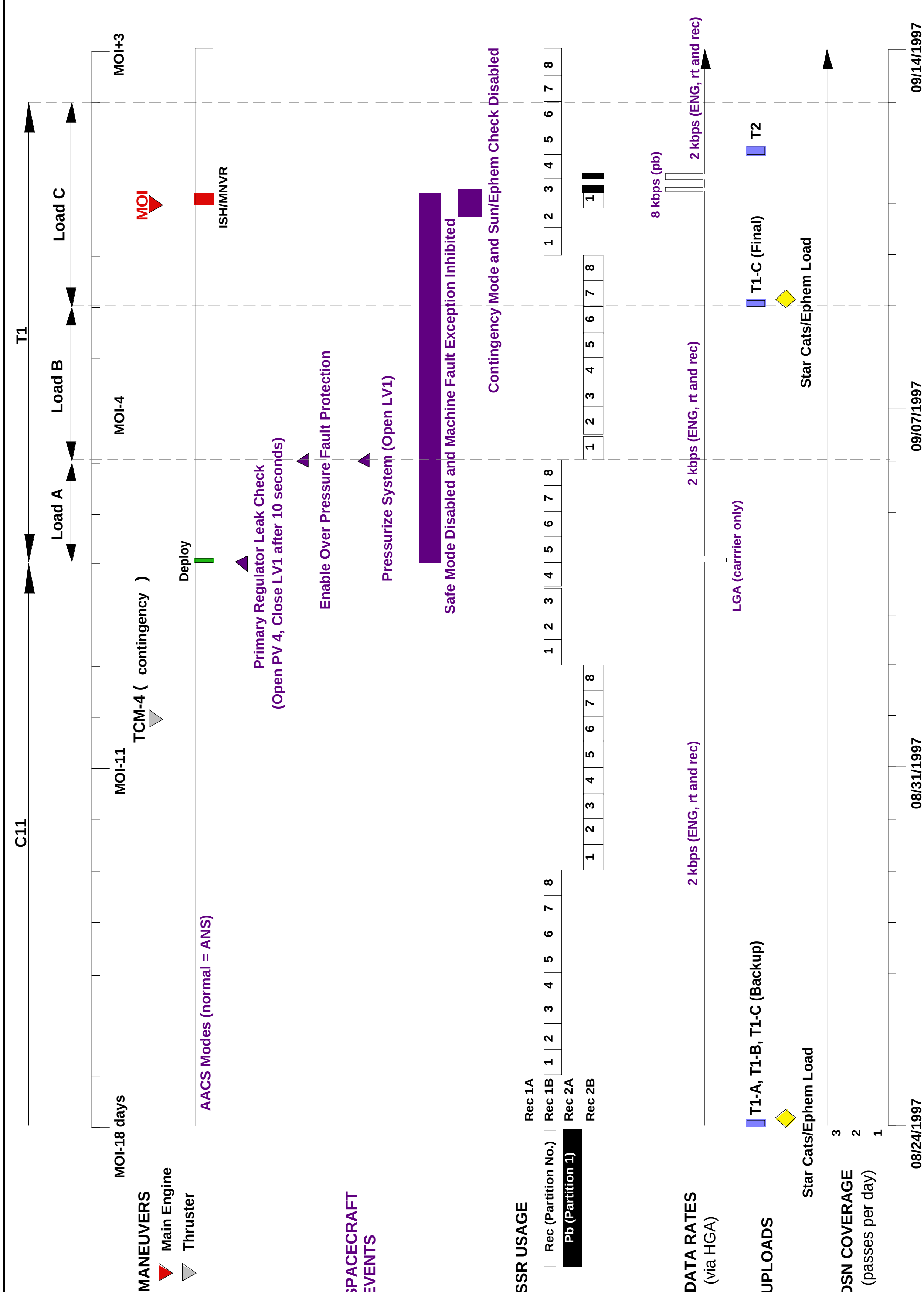
Table 4.2-2 T1 Sequence State Table

	Initial State	Transition States	Final State
Spacecraft Attitude	ANS	ISH / DEPLOY (Load A) ISH / MNVR (Load C)	ANS
Antenna	HGA		HGA
CDU rate	125 bps		125 bps
Data Mode	ENG 2 kbps		ENG 2 kbps
EDF Mode	ENGINEERING		ENGINEERING
Modulation Index	72.4°		72.4°
Ranging Modulation	ON		ON
Telemetry Modulation	ON		ON
Noncoherent Mode	OFF		OFF
USO	ON		ON
PDS	OFF		OFF
MAG	OFF		OFF
ER	OFF		OFF
MR	OFF		OFF
MOC	OFF		OFF
MOLA	OFF		OFF
TES	OFF		OFF
SSR recorder 1A	OFF	ON, RECORD (Load C), PB (Load C)	OFF
SSR recorder 1B	ON,STANDBY	ON, RECORD (Load C)	ON, STANDBY
SSR recorder 2A	OFF		OFF
SSR recorder 2B	ON, STANDBY	ON, RECORD (Load B)	ON, STANDBY

--- Special States ---

Propulsion System	Pressurant Isolated (PV 5 and LV1 closed)	Propulsion System Pressurized (PV 4 and LV 1 opened)	Propulsion System Pressurized (PV 4 and LV 1 opened)
Safe Mode	Enabled	Disabled	Enabled
Machine Fault Exception	Enabled	Disabled	Enabled
Contingency Mode	Enabled	Disabled	Enabled
Sun Monitor Ephemeris Check	Enabled	Disabled	Enabled

Figure 4.2-1 T1 Sequence Timeline



4.3 T7 Sequence Description

The T7 sequence is the sequence which configures the spacecraft for mapping operations. Included in this sequence are the HGA deployment and calibration, transition to mapping attitude control and the payload turn on and checkout. Each of these events has been placed into a separate load in order to allow assessment time by the ground prior to the uplink window of the next load.

Load A HGA Deployment

After verification of OTM1 in Sequence T6, Load A of T7 is uplinked and begins execution at ABX+174 days, for the open of the launch period. The first day of the load commands the isolation of the oxidizer system using the PRESSURE block. The bipropellant propulsion mode is not required for the remainder of the mission. The PRESSURE block switches the spacecraft to thruster control mode to maintain a desired inertial attitude as the pyro is fired. Consequently the HGA link cannot be maintained in this mode. Therefore the load additionally switches from the HGA to the LGA for the brief duration of the pyro firing event and turns off telemetry modulation to the MOT, to boost the strength of the carrier signal received by the ground. In order to maintain 2 kbps engineering telemetry recording on the SSR, the EDF is left in Engineering Mode. Upon returning to ANS, the load switches back to the HGA and reenables telemetry modulation to the MOT.

Day 2 of the sequence load commands the deployment of the HGA boom to its mapping configuration. This is accomplished with the HGADPLY block. The block switches to thruster control mode to maintain a desired inertial attitude during the deployment. The attitude is selected to ensure the primary LGA is within view of Earth for most of the boom deployment. Communications are reconfigured for emergency 10 bps downlink and 7.8125 bps uplink over the LGA in the event the HGA does not deploy properly. Once the boom has deployed, the block commands the HGA GDE to point the HGA back to Earth and the attitude control state is switched back to ANS. Communications will remain over the LGA when back in ANS until commanded by the ground. The ground switches back to the HGA after verifying the proper deployment of the HGA based on hinge potentiometer telemetry and HGA uplink AGC.

Upon verification of the HGA deployment, a mini-sequence is uplinked and begins execution on day three of the sequence to calibrate the HGA gimbal pointing. The mini-sequence contains the HGA_PAT activity, as described in Section 2.4.4, to determine the precise alignment of the HGA boresight. Based upon the resulting gain map, appropriate offsets to the gimbals' zero reference point are uplinked by the ground as required.

Load B Mapping Transition

Load B begins execution on day four to command the spacecraft to the mapping nadir pointed attitude control state. This transition occurs over two days. On the first day of the load, the IMU is first commanded to low rate mode. Next the MHSA is turned on and its redundancy management logic enabled, in order to warm up the sensor for 24 hours prior to the actual transition to nadir pointing. This transition is accomplished with the MAPFIG block the next day. The MAPFIG block is timed to begin execution as the spacecraft enters eclipse. The block first commands the attitude control state to ISH mode to perform a set up turn for transition to the mapping attitude control mode. This ISH turn effectively points the spacecraft +Z axis at the center of Mars while providing sun avoidance protection for the payload during the turn. Once the set up turn has been completed the block commands the solar arrays' GDEs and the HGA GDE to their respective set up orientations from which to enable autonomous tracking upon exiting solar eclipse and Earth occultation, respectively. The mapping phase star catalogue and ephemeris are next enabled by the block. The local vertical offset flag, used during CSA/Backup mode in aerobraking to keep the spacecraft -X axis nadir pointed is also disabled. Attitude control is then switched to CSA/Backup mode. Once the MHSA has acquired “Mars Lock”, in which all four quadrants are viewing Mars, attitude control is autonomously switched to Primary mode.

Finally, at eclipse and occultation exit, respectively, autonomous gimbal tracking is enabled for the solar arrays and the HGA.

Load C Payload Activation

After allowing a day for spacecraft characterization in the mapping configuration, Load C is uplinked to the spacecraft and begins execution on the seventh day of the sequence. Load C activates the payload and performs a mapping rehearsal in preparations for the start of mapping. The PDS and instruments are powered on the first day. The spacecraft equator crossing computation capability is next enabled, in which a ground defined resident utility script is updated by the flight software for the next two ascending node crossing times and activated about 10 minutes before the first node crossing. The activated script issues the PDS equator crossing time which is broadcast to the instruments. The mapping record activity, MAP_REC, defined in Section 2.4.2, is next initiated by the load to start 24 hour mapping recording on SSR recorders 1A and 1B. The PDS RAM is loaded and instrument commands uplinked by the science teams to configure their instruments.

The next day a rehearsal of the mapping science data return strategy is commanded. First the AEM script address is updated to the mapping science playback script, to enable autonomous activation of the playback of the previous days recorded telemetry as the spacecraft exits occultation. This strategy is described in further detail in Section 5.0. The MAP_REC activity is initiated to record the current days science telemetry.

Table 4.3-1 T7 Sequence Summary

Sequence Name: Mapping Transition Sequence

Mission Phase: Orbit Insertion

Start Date: 16:00:00 MOI+174 days (UTC ERT)

End Date: 16:00:00 MOI+186 days (UTC ERT)

Duration: 12 days

DSN Coverage: Continuous

Uplink Windows:

Load A:	04:00:00	MOI+174	to	12:00:00	MOI+174
Load B:	04:00:00	MOI+178	to	12:00:00	MOI+178
Load C:	04:00:00	MOI+182	to	12:00:00	MOI+182

Load Boundaries:

Load A:	16:00:00	MOI+174	to	16:00:00	MOI+178
Load B:	16:00:00	MOI+178	to	16:00:00	MOI+181
Load C:	16:00:00	MOI+181	to	16:00:00	MOI+186

	Load A	Load B	Load C
Duration (days):	4	3	5
Major Activities:	NTO Isolation, HGA Deployment and Calibration	MHSA Turn on, Transition to Nadir Pointing	Payload Activation
Blocks/ Activities Used:	PRESSURE HGADPLY COMM CRS_REC HGA_PAT	MAPFIG	MAP_REC (6) MAP_PB (4) MAP_RT (4)
Realtime Uploads:	Star Tables and Ephemeris Tables	Mapping Star Tables and Ephemeris Tables	

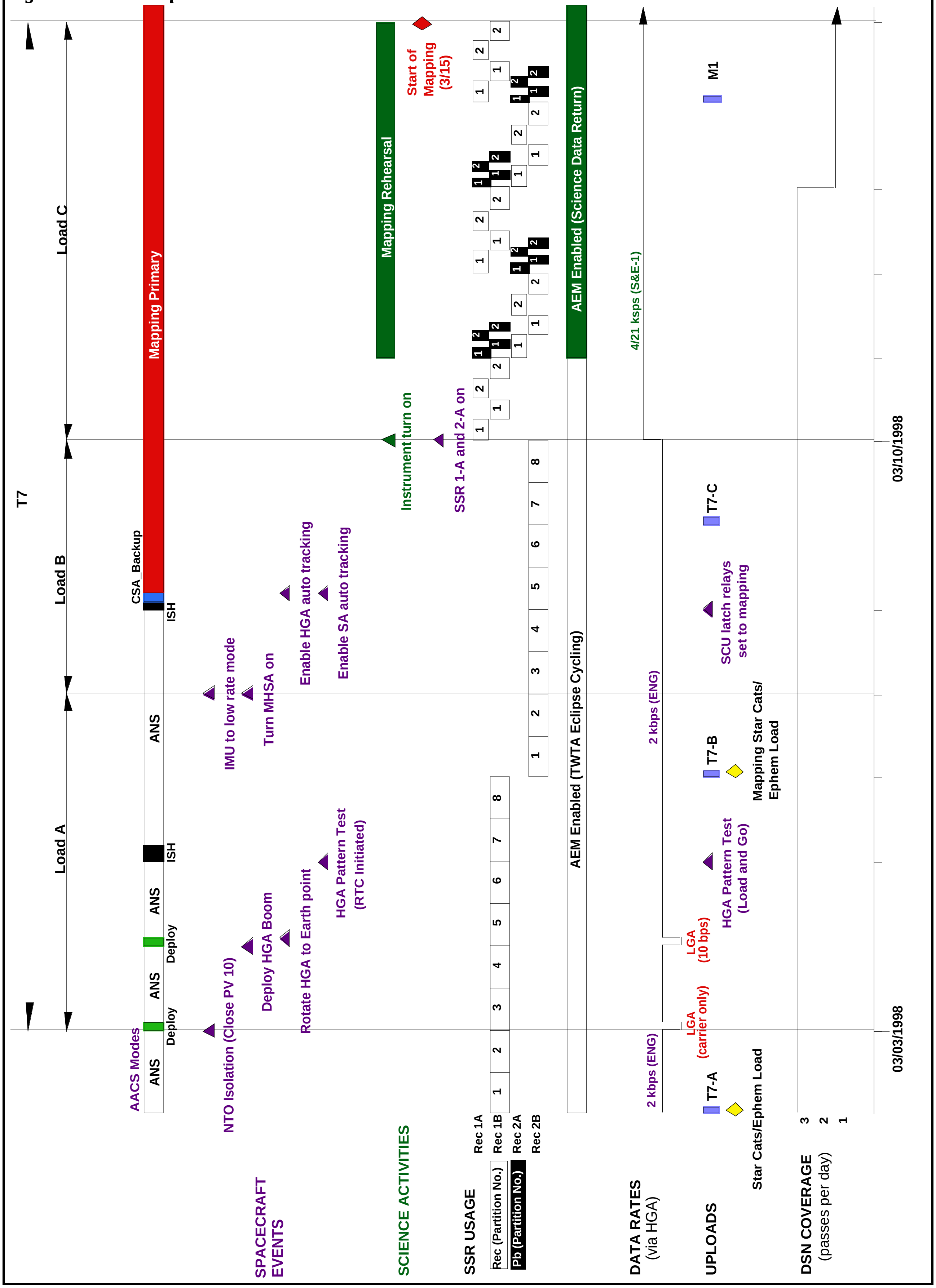
Table 4.3-2 T7 Sequence State Table

	Initial State	Transition States	Final State
Spacecraft Attitude	ANS	ISH/DEPLOY (Load A) CSA B/U (Load C)	Mapping (Primary)
Antenna	HGA	LGA (Load A)	HGA
Autonomous Eclipse Management (AEM)	enabled for TWTA cycling		enabled for mapping science data return
CDU rate	125 bps	7.8 bps (Load A)	125 bps
Data Mode	ENG 2 kbps	ENG 10 bps (Load A) ENG 2 kbps (Load A)	S&E-1 4 ksps
EDF Mode	ENGINEERING	EMERGENCY (Load A)	MISSION
Modulation Index	72.4°	42.3°	72.4°
Ranging Modulation	ON		ON
Telemetry Modulation	ON	OFF (Load A)	ON
Noncoherent Mode	OFF		OFF
USO	ON		ON
PDS	OFF		ON
MAG	OFF		ON
ER	OFF		ON
MR	OFF		OFF
MOC	OFF		ON
MOLA	OFF		ON
TES	OFF		ON
SSR recorder 1A	OFF	ON, RECORD	ON, RECORD
SSR recorder 1B	ON,STANDBY	ON, RECORD	ON, STANDBY
SSR recorder 2A	OFF	ON, RECORD	ON, STANDBY
SSR recorder 2B	ON, STANDBY	ON, RECORD	ON, STANDBY

--- Special States ---

Propulsion System	Propulsion System Pressurized	Oxidizer Isolated	System Pressurized, Oxidizer Isolated

Figure 4.3-1 T7 Sequence Timeline



4.4 Aerobraking Sequencing Strategy

4.4.1 Aerobraking Events and Blocks Overview

Aerobraking requires a sequencing strategy tailored to the repetitive, yet time critical and dynamic nature of this period. Two critical but routine events must be performed by the spacecraft to successfully accomplish aerobraking. The first of these events is the passage of the spacecraft through the drag portion of each orbit, centered about periapsis, in order to effect the necessary orbital energy loss to achieve the mapping orbit. The second critical event is the Aerobraking Maneuver, or ABM, which is a propulsive maneuver, utilizing the thrusters, executed as required at apoapsis to maintain the periapsis altitude within a defined corridor. Both of these events are illustrated in Figure 4.4-1 and described in further detail below.

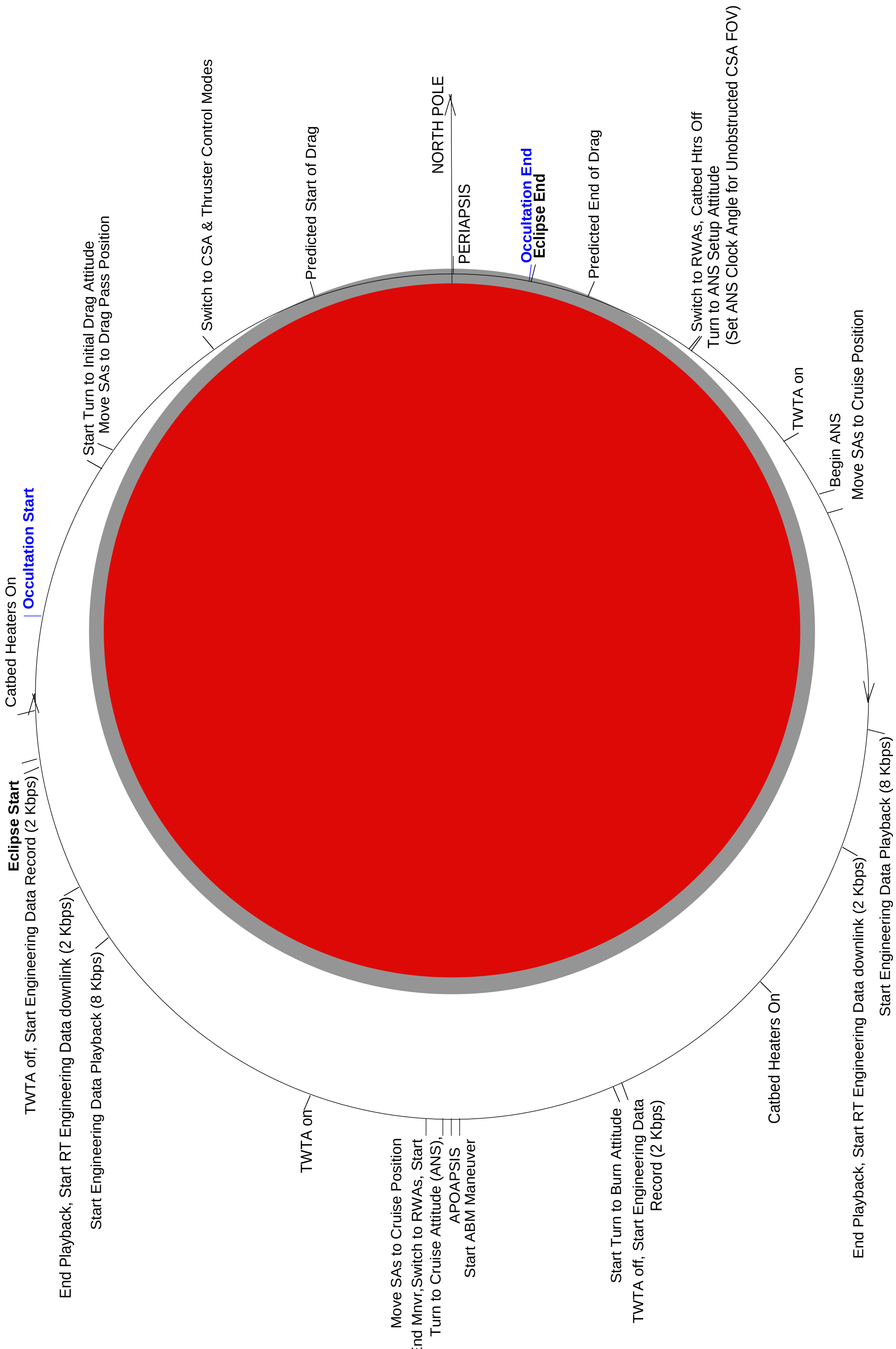
Drag Pass

The configuration of the spacecraft for the drag pass is accomplished with the AEROBRAKE block. All commands executed in the block are timed relative to the predicted start of the drag period. Additionally a delay time, normally five minutes, is added to the start and end of the predicted drag pass to accomodate navigation timing uncertainty and unexpected increases in atmospheric density. The block normally begins by warming up the catbed heaters of the thrusters for 20 minutes. Normally, 9.5 minutes prior to the pre-drag delay segment, recording of high rate engineering telemetry is initiated on one of the recorders and the transmitter turned off to conserve power. Beginning around the six hour orbit period, the orbit becomes eclipsed from the sun for up to a maximum of 41 minutes around periapsis. From this time on, the transmitter is turned off when the spacecraft enters eclipse.

Seven and a half minutes prior to the pre-drag delay segment, the spacecraft initiates a turn to the desired starting attitude for the start of the drag pass, utilizing the AACS ISH mode. This drag pass starting attitude puts the spacecraft -Z axis in the direction of the incoming atmospheric flow and the -X axis along the nadir direction. One minute after initiating the turn, the solar panels are commanded to their drag pass orientations, in which the backside of the panels are placed into the flow, but canted 30 degrees back towards the +Z axis in order to move the center of pressure aft of the spacecraft center of gravity. This orientation ensures that the spacecraft is in an aerodynamically stable attitude while providing a drag surface sufficient to accomplish aerobraking. One minute prior to the pre- drag delay segment, the spacecraft is commanded to the CSA/AB mode in which the AACS software utilizes a ground loaded spacecraft ephemeris to maintain the desired nadir orientation during the drag pass. Star processing is also disabled at this time and the spacecraft attitude is propagated with the gyros during the drag pass.

Seconds prior to the start of the pre-drag delay segment, the thrusters are reenabled and armed and actuator control switched from the reaction wheels to the thrusters. The default thruster control gains for aerobraking allow a wider deadband (15 degrees) to minimize hydrazine consumption while maintaining adequate control authority during the pass. The RWAs are also commanded to a tach hold mode at their current speeds. At the predicted periapsis time, the wheel speeds are commanded to zero to ensure their maximum momentum storage capability upon completion of the drag pass. At the predicted end of drag, the "end of drag pass" indicator is set, causing a switch to a post drag thruster gain set, in preparation for switching back to RWA control. Upon completion of the post-drag delay segment, actuator control is switched back to the RWAs, the thrusters disarmed and disabled, and their catbed heaters turned off.

Figure 4.4-1 Sample Aerobraking Orbit Profile



At this time the block has an option to either return immediately to the normal ANS attitude and regain downlink or to perform an intermediate turn, using the ISH mode, to set up a desirable CSA clock angle from which to initiate array normal spin. For the short orbits, under 3 hours, this is critical for identifying stars and updating the attitude immediately after the drag pass, when Mars may obstruct the CSA field of view if ANS is commanded directly. The Project has decided to additionally utilize this option for orbit periods greater than 10 hours to perform science observations immediately after the drag pass before returning to ANS. Upon completion of the post-drag intermediate turn, the spacecraft is commanded back to ANS.

Upon reacquiring ANS, the transmitter is turned on and a period of realtime high rate engineering downlink is initiated in order to immediately ascertain the health and status of the spacecraft. Upon completion of this realtime period, the recorder is commanded to playback the recorded high rate engineering telemetry from the drag pass. For the longer orbits, the block has an option to perform a second redundant playback of this data at a desired offset from the first one, in order to protect against a possible anomaly at the DSN tracking complex. Upon completion of the playback/s, realtime high rate engineering telemetry is resumed.

ABM

The purpose of the ABM is to maintain the periapsis altitude of the spacecraft within a desired atmospheric density corridor, bounded at the top by the minimum drag required to achieve the mapping orbit and at the bottom by spacecraft control and thermal limits. ABMs are performed during the walkin period of aerobraking to achieve the desired periapsis corridor and as needed during the main phase to maintain it. Because the periapsis latitude at the start of aerobraking begins north of the equator and continues to move towards the North Pole, the effect of the oblateness of Mars is to naturally raise the periapsis altitude. Therefore a typical main phase ABM is performed to lower periapsis. It is possible that ABMs may be executed during the main phase to raise periapsis due to an unexpected increase in atmospheric density (e.g., a dust storm). During the walkout period, as periapsis moves over the North Pole and back down the other side, in the absence of maneuvers periapsis is naturally lowered. To maintain a three day lifetime during walkout, ABMs are performed daily to raise periapsis to the top of the corridor. The three days provides sufficient margin to recover the spacecraft before it would crash into the planet, in the event of an anomaly which would prohibit an ABM from being performed (i.e., contingency mode entry).

The ABM is executed by the block of the same name.

4.4.2 Sequence Implementation

Drag Pass

Prior to the start of aerobraking, the AEROBRAKE block is executed with an initial set of block parameters and the resulting command script (or scripts, though this is still TBD) is then uploaded to an area of the sequencing memory reserved for reusable mission or phase dependent scripts. Commanding of the drag passes each orbit is accomplished by loading sequences containing script activation or “trigger” commands for this master drag pass script. The trigger commands will contain the memory address of the drag pass script, the required start time relative to periapsis and the updated timetag in the script corresponding to the drag duration. These data are provided by the navigation team in the Orbit Propagation, Timing and Geometry (OPTG) file.

Until the orbit period decreases to approximately less than ten hours, navigation can only predict ahead one orbit to meet the periapsis timing prediction requirement of 225 seconds. During this time period, approximately two months in duration, a sequence is uploaded every orbit containing a single trigger command with the required start time relative to the predicted periapsis time. From the ten hour orbit period through the remainder of aerobraking, navigation can predict ahead two or three orbits and meet the required periapsis timing accuracy. During these time periods the uplinked sequences will contain several trigger commands, with a possibility of several extra or backup trigger commands to protect against a missed upload.

Regardless of whether it is early or late in aerobraking, the actual number of commands contained in these sequences is very small and their duration no more than several hours. Therefore, the trigger commands will actually be loaded in a “mini-sequence”. As the name suggests, mini-sequences are simply smaller sequences, in size and duration, than a normal sequence. A separate area of the stored sequence buffer area is reserved for these mini-sequences. As will be discussed later, a normal sequence load, containing science data collection commands will be maintained onboard for most of the first two months of aerobraking. Placing the drag pass trigger commands in separate mini-sequences simplifies the memory management.

In addition to the orbit by orbit drag pass script updates managed by the trigger command generation process, the on-board master drag pass script will be periodically updated on the ground and reloaded due to various block options selected as aerobraking progresses. Table 4.4-1 lists the AEROBRAKE block parameters, their definitions, and their estimated update frequency.

ABM

The means of sequencing the ABMs is similar to that described above for the drag pass script. A master ABM script is generated from the ABM block, by inputting an initial set of parameters, and the resulting command script is loaded in the mission and phase dependent area of the sequencing memory. When the operations team determines that a maneuver is required, a trigger command is generated containing the ABM script memory address, the desired script start time relative to apoapsis, and the desired maneuver control flight software parameters, consisting of the maneuver ΔV magnitude and burn direction. At the desired time, the script is executed and the pre-existing values for these parameters are overwritten by the new uplinked values contained in the trigger command.

Unlike the master drag pass script, the master ABM script, once initially loaded, will not normally need to be regenerated and reloaded by the ground, except in the event of anomalies that may drive the selection of various backup options in the block.

Other Events

A more traditional sequence may also be loaded onboard the spacecraft for non critical stored commands. This "underlying" sequence is used primarily for recording and playing back in-situ science telemetry collected throughout the orbit by the MAG, ER and TES and the science telemetry acquired upon completion of the drag pass prior to returning to ANS as described in the previous section. The sequencing of this science data collection and return is straightforward, consisting mainly of recording S&E-1 telemetry on a separate recorder unit throughout most of the orbit and playing back once per orbit so as not to interfere with the drag pass and ABM events. (Note that the engineering data rate remains at the high (2000 bps) rate throughout aerobraking and as such the EDF does not provide engineering packets to the PDS to be merged with the science telemetry.) Because the exact orbit event timings are not precisely known when this underlying sequence is developed, the sequence duration is expected to be on the order of about a week long in order to provide enough timing margin to account for this uncertainty and the decreasing orbit period over this time, to keep the science data playback from interfering with the critical aerobraking events. The science telemetry is recorded at the low (4000 sps) rate and played back at the highest playback rate supported by the link (42667 sps) in order to minimize the amount of time in the orbit without realtime high rate engineering telemetry.

TABLE 4.4-1 AEROBRAKE BLOCK INPUT PARAMETERS

Parameter No./Name	Definition	Estimated Update Frequency
1.1 DELAY_DUR	Navigation / atmospheric periapsis prediction uncertainty	Updated once at around 10 hour orbit period when navigation predicts multiple orbits ahead.
1.2 CATBED_DUR	Catbed heater warmup duration	Possibly updated once for power margin at 6 hour orbit period.
1.3 SLEW_DUR	Slew duration to achieve drag pass attitude	If needed due to anomaly.
1.4 TWTA_OFF	TWTA off time relative to the drag start	Weekly after 6 hour orbit period.
1.5 TWTA_ON	TWTA on time relative to end of drag pass	Maybe once at end of walkout for open of the launch period.
1.6 REA_SELECT	REA thruster string selection	If needed due to anomaly.
1.7 TRANSMIT	Flag used to enable transmit through drag pass	None. Provided as a backup option.
1.8 AACS_MODE	Desired attitude control mode for drag pass	None. Always set to CSA nadir pointing option. ISH option provided as backup.
1.9 DRAG_QUAT	Initial drag pass set up attitude	Weekly or mor e frequent during walkout.
1.10 SLEW_RATE	Desired pitch rate if ISH mode used during drag pass	None. Provided as backup option to CSA mode.
1.11 SLEW_VECT	Desired pitch vector if ISH mode used during drag pass	None. Provided as backup option to CSA mode.
1.12 CSA_ISH	Flag used to enable post drag pass slew for Mars CSA FOV obstruction or science observations	None. Always set to TRUE as primary option.
1.13 CSA_QUAT	Desired quaternion for post drag pass slew	Weekly or more frequent during walkout.
1.14 CSA_DUR	Desired duration of post drag pass slew	Updated once. Initially set for science turn and updated for ANS clock angle setup turn after 10 hour orbit period.

TABLE 4.4-1 AEROBRAKE BLOCK INPUT PARAMETERS (continued)

Parameter No./Name	Definition	Estimated Update Frequency
1.15 SAP_AZ_DRAG	+Y SA azimuth gimbal target for drag pass	If needed due to anomaly
1.16 SAP_EL_DRAG	+Y SA elevation gimbal target for drag pass	If needed due to anomaly
1.17 SAM_AZ_DRAG	-Y SA azimuth gimbal target for drag pass	If needed due to anomaly
1.18 SAM_EL_DRAG	-Y SA elevation gimbal target for drag pass	If needed due to anomaly
1.19 SAP_AZ_ANS	+Y SA azimuth gimbal target for ANS	If needed due to anomaly
1.20 SAP_EL_ANS	+Y SA elevation gimbal target for ANS	If needed due to anomaly
1.21 SAM_AZ_ANS	-Y SA azimuth gimbal target for ANS	If needed due to anomaly
1.22 SAM_EL_ANS	-Y SA elevation gimbal target for ANS	If needed due to anomaly
1.23 REC_SEL	Desired recorder unit to record drag pass telemetry	None. Set once at start of aerobraking.
1.24 PB_RATE	Desired playback rate	Once. Initially set to 8 kbps. Reset to 21 ksps for walkout.
1.25 PB_DELAY	Desired delay time between transmitter turn on and start of drag pass telemetry playback	Once. Initially set to 15 min. Reset to 10 for orbit periods under 2.5 hours.
1.26 2ND_PB	Flag used to enable second redundant playback of drag pass telemetry.	Once. Initially set to TRUE. Reset to FALSE for orbit periods under 8 hours.
1.27 PB2_DELAY	Desired delay time between end of first drag pass telemetry playback and the start of the second.	Approximately every 3 weeks until orbit period equals 8 hours.
1.28 PB_INDEX	Desired telemetry modulation index for selected playback rate.	Once. Initially set for 8 kbps. Reset for 21 ksps for walkout.
1.29 RT_INDEX	Desired telemetry modulation index for realtime rate.	None. Initially set for 2 kbps realtime downlink.
1.30 MOT_STATUS	Flag used to determine which MOT to command to.	If needed due to anomaly.
1.31 EDF_SIDE	Flag used to determine which EDF side to command to.	If needed due to anomaly.
1.32 XSU_STATUS	Flag used to determine which XSU side to command to.	If needed due to anomaly.
2.0 PERIAPSIS	Predicted time of periapsis	Each orbit
2.1 DRAG_DUR	Predicted drag pass duration	Each orbit.

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5. Mapping Phase

5.1 Overview of Mapping Data Return Strategy

There will be two modes for collecting science data during mapping. The primary mode is to continuously record data on the solid state recorders and play it back to the Earth during a daily 10 hour tracking station pass. The secondary mode is to return realtime, high-rate telemetry at the 40-ksps rate during an additional tracking pass, normally scheduled once every third day. Included with both modes are radio science occultation experiments which are performed as the spacecraft exits and enters occultation each orbit of the tracking pass. Both modes are described in greater detail in Sections 5.1.2 and 5.1.3 below.

Sequencing during the mapping phase is characterized by the repetitive nature of these two modes. It is possible to take advantage of this repetitive nature and simplify mapping operations by utilizing spacecraft autonomous eclipse entry detection in sequencing the science data return. This autonomous eclipse management (AEM) capability allows ground defined command scripts to be initiated autonomously by the spacecraft. Therefore AEM triggered scripts will have far more accurate timing associated with them than if they were initiated by the ground. Also since the ground defined data return scripts will reside on-board the spacecraft the size of the sequences decreases significantly allowing for faster and more efficient sequence generation and validation. A detailed description of how AEM works and how it is to be used in sequencing the mapping data return is provided in Section 5.2.

5.1.1 Data Collection Strategy - Recorded Data

The basic strategy for collecting science data during the mapping phase is to record 24 hours of science data onto the recorders and then play it back in one 10 hour DSN tracking pass on each day. With appropriate record and playback rates, data can be collected continuously and only one tracking pass is required on each day. Three pairs of "standard" record and playback rates have been defined for this normal mode of operation. The playback rates are 21.3, 42.7, and 85.3 ksps and the corresponding record rates are 4, 8, and 16 ksps, respectively. The ratio of the two rates was selected because in a typical 8-hour DSN tracking pass, due to Earth occultations, a minimum playback time of roughly 4.5 hours is available to return 24 hours of recorded data. The playback rates were selected to cover the range of expected telecom capability as the Earth-to-Mars distance varies over the mapping phase. To ensure full coverage of the radio science occultation events and to provide some realtime telemetry from the spacecraft for health assessment and command verification, the project has requested a daily 10-hour DSN tracking pass. It has been assumed that only one playback rate will be used over each tracking pass, and that the rate will not be increased as the tracking elevation increases. The playback could be completed more quickly (or more data could be returned), if the playback rate was adjusted over the tracking pass, but this would increase the complexity of planning the data return.

Each of the four recorder units (two units per SSR) can store up to 52 hours of data at the 4 ksps record rate and up to 13 hours at the 16 ksps record rate. At the 16 ksps record rate two recorders are required to store 24 hours of data. At the 4 and 8 ksps record rates, there is a substantial margin in the record capacity, and this will allow playbacks to be scheduled at any time during a 24-hour period without approaching the capacity. There is less flexibility for scheduling the playback passes at the 16-ksps record rate because the total SSR capacity is only 52 hours. Normally, when the tracking site for the playback is changed on the next day, it will have to move earlier in time rather than later.

Because the spacecraft goes into occultation each orbit for most of the mapping phase, the playback must be broken into segments and sent down over more than one orbit. Additionally due to power constraints, the spacecraft cannot continuously transmit throughout the entire orbit and the transmitter must be turned off for most of the solar eclipse portion of the orbit, which happens to mostly overlap the occultation period. Therefore even during the period of the mapping phase when the spacecraft is never occulted from Earth, the data playback must still be broken up into segments over multiple orbits. In determining the minimum playback time available per orbit, however, the limiting case is when the spacecraft is occulted from Earth, since additional time in the orbit must be allocated to the radio science experiment.

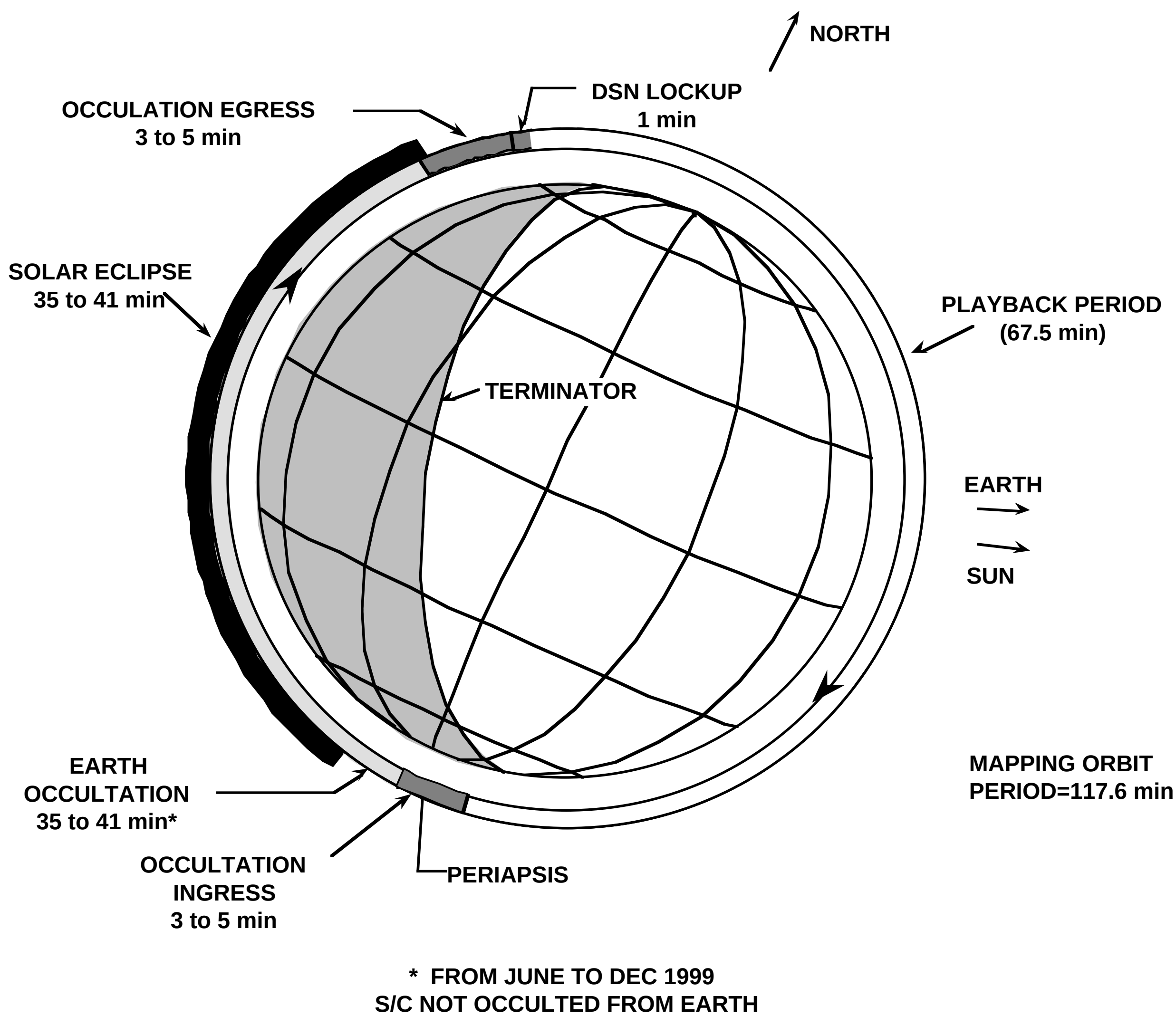
The minimum available playback time on each orbit is determined by the orbit period, minus the time the spacecraft is in Earth occultation minus the time allocated for the radio science experiment, DSN lockup time, and any navigational uncertainty. The mapping orbit has a period of about 118 minutes. The time in Earth occultation is typically about 41 minutes (maximum of 41.5 minutes). Some additional time when the spacecraft is entering and exiting occultation will be used for the atmospheric occultation experiment. The radio science requirements are to record occultation data, from the surface to an altitude of 200 km plus 100 seconds, for every ingress and egress event that occurs during a tracking pass. Because telemetry modulation will be turned off for this experiment for maximum signal strength, the duration of this experiment subtracts from the available playback time. Over about the first 400 days of the mapping phase, the occultation experiment will typically require 8.5 minutes of transmission per orbit. Ignoring the DSN lockup time and navigation uncertainty for now, the minimum playback time available per orbit is about 67.7 minutes.

In order to effectively utilize AEM to initiate the data playback, it is desired to have a fixed playback duration per orbit. In a ten hour tracking pass there are approximately five orbits. The non-occulted portion of the orbit is defined to be the Earth View Period or EVP. Depending on where in the orbit the spacecraft is at the start of the tracking pass only four of the EVPs are guaranteed to be in view of the Earth for their entire duration. The fifth orbit may be split into two parts with a partial EVP at the beginning of the tracking pass and the other at the end. Therefore a four orbit data playback strategy is required if it is desired to utilize a fixed orbit playback duration. At the 5.333 playback to record ratio, 24 hours of recorded telemetry can be played back in 270 minutes. Dividing this number by four for the number of playback orbits yields a playback duration per orbit of 67.5 minutes. Note that this just fits in within the minimum playback time available per orbit as determined above. Figure 5.1-1 illustrates the typical mapping playback orbit profile.

The first orbit of a playback pass will be used to downlink realtime S&E-1 data in order to provide some realtime engineering telemetry for a spacecraft health check and to provide command verfication for uplinks. These data are redundant to the science data being recorded and subsequently played back on the next day’s tracking pass. The DSN requires a maximum of five minutes to lockup the telemetry stream on the first orbit. After the playback orbits have been completed, any additional time in the tracking pass will also be used for realtime S&E-1 telemetry. This provides additional data for health assessment and command verification.

For subsequent orbits after the first one in a tracking pass, the DSN requires one minute to lockup on the telemetry stream. Because the playback must begin immediately upon completion of the radio science observation at occultation exit in order to meet the 67.5 minute orbit playback duration requirement, the DSN will be locking up on the playback telemetry. It is desired to “rewind” the recorder to ensure that no new data is lost during this lockup and to recover a partial telemetry frame received at the end of the previous playback orbit. However, since the recorders do not possess a rewind capability, the only way to accomplish this is by overlapping the data on a second recorder. This adds some operational complexity in managing the recording of the data. Rather than recording 24 hours on a single recorder at the lowest record rates or 12 hours at the 16 ksps record rate, recording is performed in four 6 hours segments, where each segment equates to a single 67.5 minute playback orbit. Each record segment will overlap the previous by 10 minutes. The ten minutes allows two frames of S&E-1 telemetry overlap to accomodate the DSN telemetry lockup and a partial telemetry frame at the end of the previous playback orbit.

Figure 5.1-1 Typical Profile for Playback Orbit



5.1.2 Data Collection Strategy - Realtime Data

The project has included a realtime data rate of 40 ksps (34.9 kbps) to permit the return of some high-bandwidth data that would otherwise be constrained to the lower record rates. The project policy is that an additional 34-meter (HEF) antenna tracking pass will be scheduled approximately every three days over the mapping phase to return data at the realtime rate. This additional realtime data returned every three days augments the recorded data returned every day at the available playback rate.

A strategy for collecting the realtime data adds some complexity to the mission design. The recorded data modes provide complete coverage over each orbit and around the planet on each mapping cycle. However, the realtime data can only be collected when the Earth is in view, that is, primarily on the dayside of the planet, and when an additional tracking pass is scheduled. Only TES and MOC data are returned during realtime coverage. No specific coverage requirements have been specified for these instruments.

5.2 Mapping Sequence Implementation

5.2.1 AEM Overview and Implementation

The spacecraft has a solar eclipse detection capability called autonomous eclipse management or AEM. This algorithm resides in the flight software power task and utilizes power subsystem telemetry inputs, short circuit current, solar array current and battery currents, in a majority vote scheme to detect transits into and out of eclipse, to within 12 seconds accuracy. Upon detecting these transitions, the flight software initiates a separate ground specified pre-loaded command script for eclipse entry and exit. The egress and ingress detections and script triggers are independent of each other and can be selectively enabled or disabled.

Rather than using both the eclipse entry and the eclipse exit detection logic to initiate two separate scripts to sequence the data return events over an entire orbit, it is operationally simpler to use either one or the other to initiate a single script. In determining whether to use the eclipse exit or entry detection as the preferred trigger mechanism, it is necessary to examine the timing and geometric relationship between solar eclipse and Earth occultation for the mapping orbit. The relationship between the two is important because the data return must be timed relative to Earth occultation even though the script is triggered by eclipse detection. Two aspects of this relationship between eclipse and occultation are important in deciding how to design the AEM scripts. The first is that the eclipse and occultation periods generally overlap for most of the mission, except for late in mapping when the orbit is never occulted from Earth. The second is that occultation exit can occur either before or after the eclipse exit. This is significant because if eclipse exit is used as the trigger for the command script, it would be frequently too late since occulation exit would have already occurred. Therefore eclipse entry detection should be the trigger for the initiation of the desired command script.

From the previous descriptions of the data return strategies, two AEM data return command script candidates have been identified, one for the playback data and a second for the realtime data. These scripts are generated by the ground and loaded onboard the spacecraft in reserved area of the store sequence buffer for mission or phase dependent scripts. In order to initiate the scripts the ground needs to only enable the AEM eclipse ingress logic and set the appropriate script address, depending on whether the DSN pass is intended for the daily playback or the high rate realtime data return.

The playback data return script executes the following sequence. Upon initiation it waits for a delay period equal to the difference between the navigation predicted occultation exit time and eclipse entry time minus a transmitter turn on time sufficient to stabilize the telecom signal prior to the start of radio science. After the transmitter has warmed up, the script next configures the telecom subsystem for the radio science at egress observation by turning off telemetry modulation and commanding the MOT to one-way non-coherent mode using the USO as the downlink frequence source. After the navigation predicted radio science duration, telemetry modulation is turned back on and two-way coherent mode reenabled. Playback is immediately commanded from the selected recorder for the next 67.5 minutes., at which point the XSU is then reconfigured for realtime S&E-1 telemetry or, if the link will support it, realtime S&E-2 high rate telemetry. The script then repeats the radio science configuration commands at the proper time for the radio science observation at occultation ingress and turns the transmitter off for the eclipse period.

The realtime data return script is very similar to the playback script. Instead of issuing recorder playback commands after the radio science at egress opportunity, however, the XSU is configured to downlink realtime S&E-2 telemetry.

5.2.2 Mapping Block and Activity Descriptions

Two blocks (MAP_PB and MAP_RT) and one activity (MAP_REC) have been defined to implement the data return strategies outlined in the previous subsection. In addition to the data return blocks, two more blocks, OTM and MANLOAD, are used to perform the periodic orbit trim maneuvers required to maintain the mapping orbit.

MAP_REC

The MAP_REC activity, defined in Section 2.4.2, is used to record 24 hours of telemetry in 6 hour segments on two of the recorder units. This activity is issued every 24 hours throughout the duration of the mapping phase.

MAP_PB

The MAP_PB block is used to enable AEM for the daily science playbacks. The block start time is set to 10 minutes prior to the eclipse entry time for the first full orbit seen by the DSN station. The block first enables AEM ingress detection and sets the appropriate script address for the AEM data playback script. The script is initiated autonomously over the next four orbits to complete the playback. After sufficient time has passed to ensure the data playback script has been triggered for the fourth and last playback orbit, the block disables the eclipse entry detection logic.

In addition to managing AEM, the block also manages the HGA gimbal drive. In order to minimize hydrazine fuel consumption, the HGA is “parked”, when outside of scheduled DSN contact periods, in a position that minimizes spacecraft system momentum buildup. The block therefore has options to unpark the HGA and enable autonomous Earth tracking at the start of the playback pass and to park it again at the end.

Finally the block provides several parameter updates to the actual AEM data playback script. The first set of parameters are timing updates derived from the navigation predictions, including the delay time between eclipse entry and occultation exit and the durations of the radio science observations. The second set are recorder management parameters which are updated for each of the playback orbits. Specifically these parameters include the desired recorder and partition to playback from and the desired playback rate.

MAP_RT

The MAP_RT block is used to enableAEM for the S&E-2 high rate realtime data return every third day. Additionally this block is also used for additional realtime downlink for the first orbit of a scheduled 10 hour playback pass and if available over the last orbit after completion of the four playback orbits. The MAP_RT block is very similar to the MAP_PB block. The differences are the MAP_RT block enables a different command script to be triggered by the AEM ingress logic and allows the user to input the desired number of orbits to leave AEM enabled.

OTM and MANLOAD

The OTM and MANLOAD blocks are used to periodically perform small hydrazine orbit trim maneuvers in order to maintain the required mapping orbit. The MANLOAD block is used to load the required maneuver control parameters into the flight software, and include the desired ΔV and burn direction. The OTM block is used to execute the burn and is very similar to the hydrazine maneuver option in the MNVR block. Specific to mapping, upon completionof the burn, the attitude control is switched from ISH / MNVR to CSA_BU mode to reacquire a nadir orientation from which to lock the MHSA onto Mars and subsequently transition to Primary Mapping mode. Additionally specific to mapping, the SAs are repositioned for the burn and subsequently to a position from which to reenable autonomous tracking as the spacecraft exits occultation and eclipse, respectively.

5.3 Mapping Phase Sequence Definitions

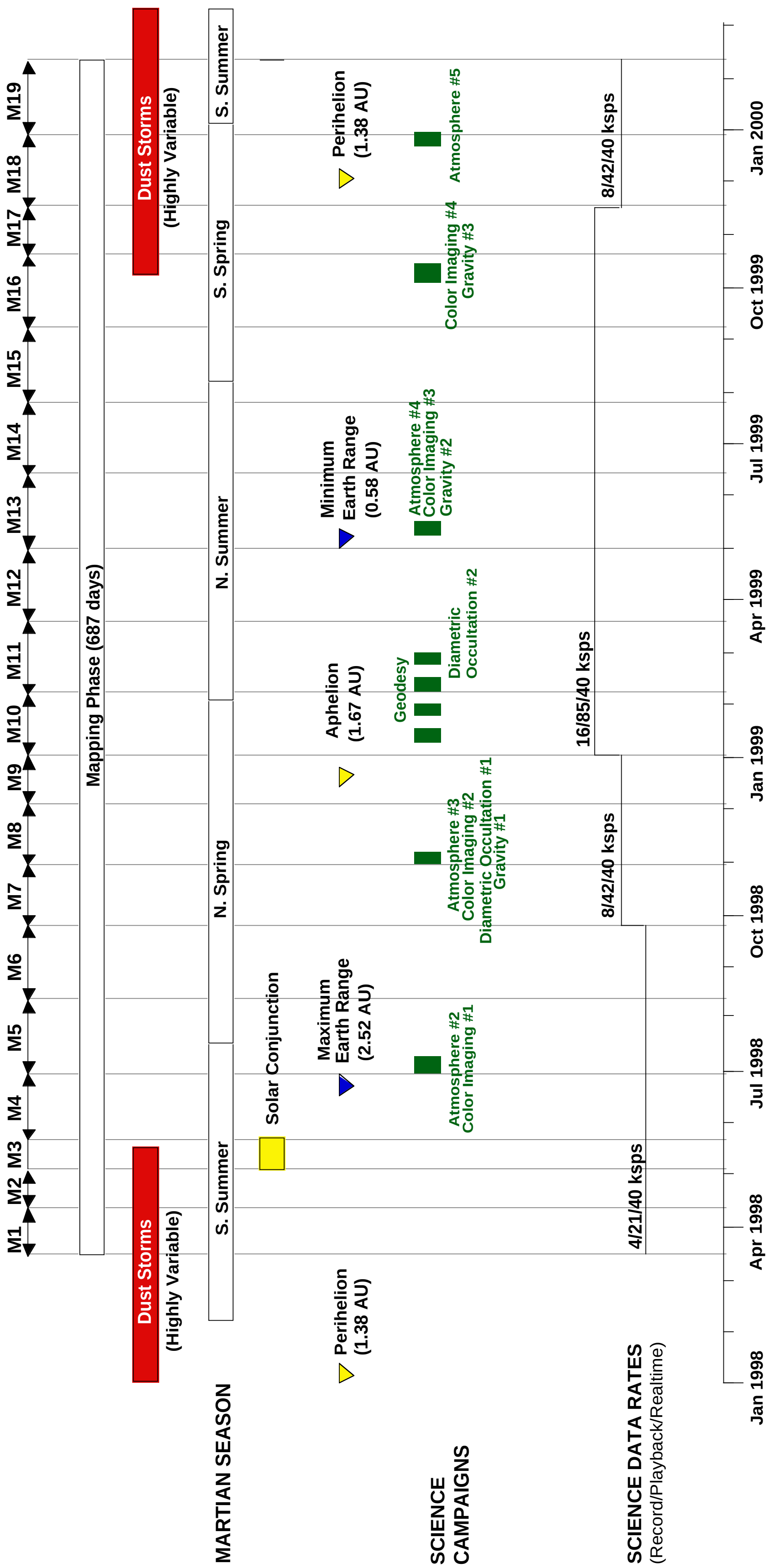
Figure 5.3.1 shows the mapping sequences overlaid on the mapping mission phase timeline. Due to the repetitive nature of the mapping phase data return strategies and the small size of the operations team, it is desired to reduce the number of sequences required to meet the mission science data return requirements. The maximum mapping phase sequence duration is limited by three factors, the accuracy of the DSN allocation predictions, the time required for the ground to generate and validate the sequences, and the accuracy of the navigation predictions. The eight week advanced DSN allocation file typically contains the most accurate forecast available to the ground for developing sequences.

One of the advantages of utilizing AEM is that the sequence development and validation time can be significantly reduced because of the much smaller sequence sizes resulting from the use of reusable onboard command scripts. It is anticipated that two weeks will be sufficient to generate a mapping sequence, which is half the time required to generate a cruise phase sequence. Subtracting the two week sequence development cycle from the eight week DSN allocation yields a maximum sequence duration of 42 days.

Although utilizing AEM results in significantly increased timing accuracy in triggering the data return event scripts, ground navigation is not completely divorced from the sequence development process. The data return script triggered autonomously by the eclipse entry detection logic must still be kept in synch with the ground predicted occultation exit time. However, because navigation does not need to determine absolute event times for eclipse entry and occultation exit times, but rather the relative difference between them, the error in this value will be very small. Although this analysis has not currently been performed, it is anticipated that the prediction error should be on the order of seconds over the duration of the sequence. If the analysis eventually determines that the error in this prediction is significantly higher, then it may be required to reduce the 42 day maximum sequence duration.

The final factor in laying out the mapping sequences is the available data rate that can be supported by the telecom link. As the Earth-Mars range changes throughout the mapping phase, the data rates are periodically adjusted. In order to simplify operations, a single record / playback data rate pair is used throughout a sequence, although this sometimes resulted in a sequence as short as 28 days. Refer to Table 2.2-3 for the record and playback rates used in each sequence.

Figure 5.3-1 Mapping Phase Timeline



5.3.1 Reference Mapping Timelines

Representative timelines for several mapping phase sequences follow in this section. Each timeline depicts a one to three day period of the selected sequence. Although actual DSN allocations are not available, representative passes are shown which are typical of the coverage expected. The sequences selected cover the range of available data rates as well as illustrating different Mars to Earth and Sun geometries that characterize unique periods of mapping affecting the sequence design (e.g. aphelion, no Earth occultations, maximum Earth range, etc.)

(For the preliminary version of the MSP only the M1 sequence reference case follows, the remaining mapping sequence reference cases will be documented in the August 1996 Final Revision)

5.3.2 M1 Sequence

Figures 5.3.2-1 (a), (b), and (c) depict a three day period during the first mapping sequence, M1. The data rates used throughout the M1 sequence are 4/21/40 ksps, respectively for record, playback and realtime. The first day (shown in figure a) represents a typical 10 hour playback pass. The MAP_REC activity is first initiated to record 24 hours of science data in 6 hour overlapped segments on recorders 2A and 2B.

The MAP_RT block is used to provide realtime 40 ksps downlink for the first EVP of the pass. The AEM script address is set to the realtime data return script and AEM ingress logic enabled 10 minutes prior tothepredicted time of the first eclipse entry of the pass. The HGA unpark option is selected at the beginning of the block to reenable HGA autonomous tracking. Prior to the next eclipse entry, the block disables AEM. The option to repark the HGA at the end of the realtime orbit is not selected since the playback orbits are to follow immediately.

The MAP_PB block is next used to perform the playback over the next four orbits the previous day's recorded telemetry on recorders 1A and 1B. Ten minutes prior to the predicted eclipse entry time, the block sets the AEM script address to the data playback script and enables AEM ingress logic. Since HGA autonomous tracking is already enabled the unpark option is not selected. AEM triggers the data playback script over the next four orbits. Playback is performed from recorder 1A on partition 1 for the first orbit, from recorder 1B on partition 1 for the second orbit, back to recorder 1A onpartition 2 for the third orbit and finally back to recorder 1B on partition 2 for the final orbit. Prior to the next eclipse entry, the block disables AEM. Because there is additional time in the DSN pass to perform an additional realtime orbit after completion of the playback the HGA park option is not selected in order to keep autonomous tracking enabled.

The MAP_RT block is executed again to perform a final realtime orbit. Note that the DSN pass finishes a little before the completion of the EVP. Upon completion of the realtime orbit the block parks the HGA in its minimal momentum buildup position.

Figure (b) covers the next 24 hour period and shows a playback pass identical to the previous day's as well as an additional pass for the high rate realtime data return. The block calls are nearly identical. For the MAP_PB block recorders 2A and 2B are used for the playback while recording continues on recorders 1A and 1B in 6 hours overlapped segments with the MAP_REC activity. The second MAP_RT block call differs only in that the number of orbits is set to 6 instead of 1 to cover the period of the 10 hour realtime pass.

The last day of activities for this reference case is shown in figure (c). The playback pass is essentially the same as the first day's. An additional four hours of DSN coverage is requested to support an OTM. For the first several OTMs performed in mapping it is desired to perform them while there is DSN converage in order to monitor the execution of the burn as well as the performance and health of the spacecraft. Later in mapping it is possible that OTMs will be performed “in the blind” or performed during periods of no DSN coverage. The OTM maneuver sequences are actually not contained within the mapping sequences but are instead executed as mini-sequences and uplinked to the spacecraft whenever a burn is required. It is anticipated that OTMs may be performed as infrequently as once every four to six weeks.

For this reference case the OTM mini-sequence is loaded and executed over the last two orbits of the scheduled 12 hour pass, after the playback has been completed. The mini-sequence contains three block calls. The first block is a MAP_RT block used to maintain realtime downlink over the additional orbit. Note that a MAP_RT block was already used in the mapping sequence itself to perform realtime over the orbit immediately following final playback orbit. The MANLOAD block is executed prior to the burn to load the required flight software maneuver control parameters. The OTM block is used to perform the burn itself. The burn is executed at periapsis of the first orbit after the final playback orbit. Realtime coverage continues on the next orbit to allow a full orbit of telemetry to assess the burn and the performance of the spacecraft.

Figure 5.3.2-1 (a) M1 Sequence Representative Timeline - 3/15/98

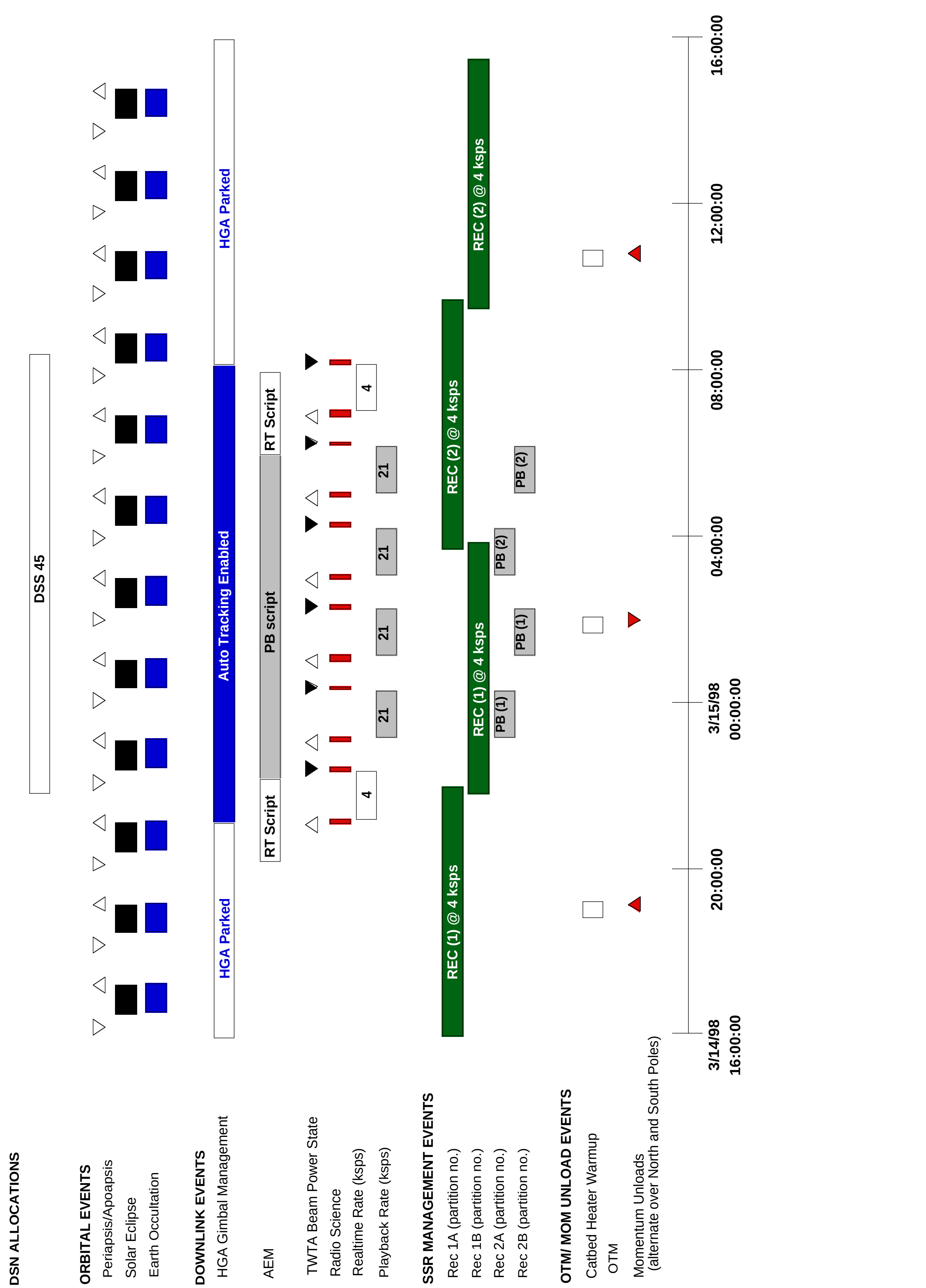


Figure 5.3.2-1 (b) M1 Sequence Representative Timeline - 3/16/98

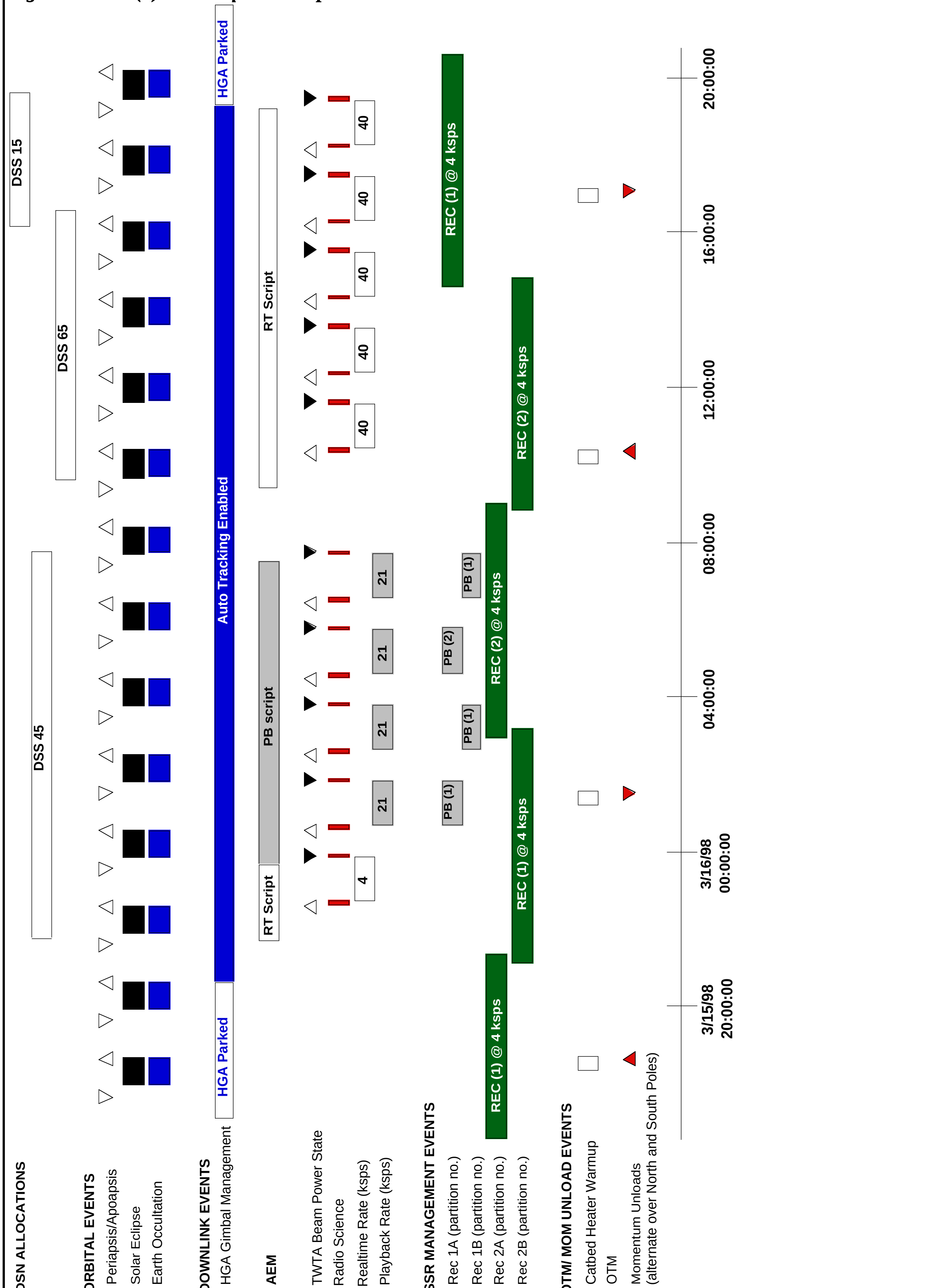


Figure 5.3.2-1 (c) M1 Sequence Representative Timeline - 3/17/98